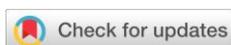


# Green education for sustainable development goals: Environmental, social, and economic resilience

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## Abstract

Although the issue of sustainability has been acknowledged by many, the structural systems of education world over have not been able to resolve the issue of incorporating green education principles that are sensitive enough to tackle issues of environmental degradation, social inequity as well as economic instability. The modeling of the modern educational systems still tends to separate the aspect of sustainability and make it a single topic not a paradigm shift towards a comprehensive resilience in all three pillars of sustainable development. This literature review attempts to explore the changing frontiers of green education and its important role in attainment of Sustainable Development Goals with the major focus on developing environmental stewardship, social equity, and economic viability. The discussion demonstrates that there are five significant pedagogical strategies, which include experiential learning ecosystems, digital sustainability platforms, community-based collaborative models, systems thinking frameworks, and transformative action competence development. The new trends are the use of artificial intelligence to achieve personalized sustainability education, gamification of environmental education, virtual reality to experience an ecological environment, blockchain to monitor sustainability credentials, and citizen science programs that would make the transition between formal and informal education. Green education has shown quantifiable behavior change effects, policy effects, innovation capability, and community stability on implementation of green education using holistic, context-sensitive strategies.

Keywords: Green education, Sustainable development goals, Social resilience, Education, Climate change.

## 1. Introduction

There is escalating climate change, the loss of biodiversity and increasing socioeconomic disparities have made education a key driver to change in society [1]. Mineralized as a holistic method of teaching, entailing the act of environmental awareness, social responsibility, and economic sustainability, green education has become a fundamental paradigm on how to attain the United Nations Sustainable Development Goals [1-2]. In contrast to the conventional environmental education where ecological awareness is the key outcome, green education is associated with the holistic attitude toward the environment health, social justice, and economic prosperity [3-5]. The modern learning environment has never had greater challenges in equipping learners to inhabit a densely evolving world where there is uncertainty of the environment, technology and social disturbance [6-8]. Conventional disciplinary boundaries and knowledge systems in compartments cannot be sufficient to meet the intricate sustainability problems that cut across sectors, scale, and temporal boundaries. Green education is a reaction to this insufficiency in that it teaches systems thinking, critical consciousness and action competence on the part of the learners of all ages and in all situations involving education. Green education is not solely required as a means of conserving the environment, but rather carries a bigger implication of intergenerational justice, cultural diversity, democratic inclusion, and economic fairness. The education systems of the world are getting more cognizant of the fact that sustainability

competencies are vital twenty first century competencies, which are just as important as literacy and numeracy. This understanding has sparked changes in the design of curriculum, pedagogical practices, assessment practices and institutional governance that puts sustainability at the centre of educational missions and not on the edges. The situation in the recent green education has been marked by increased sophistication of theoretical literature, empirical research approaches and application modalities. Scholars and professionals no longer believe in the naive methods of spreading awareness but in the models of transformative learning that undermine the general outlooks of the world, its values and behavioral patterns. This transformation recognizes that the necessity of attaining sustainable development is not only technical development but complete transformation in the way people and their societies perceive their relationship to the natural and societal environment.

The crossroad between green education and technological innovation has presented new areas of sustainability learning [9]. Digital channels help individuals in the world engage in solving environmental issues, virtual reality provide feelings of immersion in the natural environment, artificial intelligence learns the necessary path change individually, and blockchain technologies confirm the status of sustainability [7,9-10]. These technological affordances do not substitute for experimental, place-based learning which puts the abstract concept of sustainability in denser local contexts [1,11-14]. At the same time, the concept of green education tends to pay more attention to penetrating indigenous knowledge, traditional ecological practices, and varied cultural attitudes which provide alternative epistemological ways of perceiving human-nature relationships. This pluralistic practice acknowledges that sustainable development trajectories have to acknowledge the many means of knowing but confront history injustice that is found in mainstream education paradigms [13,15-17]. Decolonization of the curriculum content and teaching practices is one of the dimensions of socially just green education that is crucial. Economics has been a prominent issue in green education dialogue as the stakeholders understand that there are economical models needed in environmental and social objectives [18-20]. There is a growing integration of green into education as LSDs increasingly include principles of circular economy, sustainable entrepreneurship, competencies of green jobs, and savage commentary on economic systems that enact unsustainability. This economic aspect makes the learners not only the environmentally mindful consumers but they can be the possible innovators and change agents in the economic systems. The COVID-19 crisis had an excellent toll on green education and at the same time interfered with a regular way of education delivery and created an opportunity to introduce the innovations in remote education, outdoor education, and educational programs that are community-focused [19,21-22]. The pandemic pointed to environmental degradation, the development of zoonotic diseases, and social vulnerability and pillaged the relevance of integrated sustainability education. The post-pandemic educational reconstruction provides prospects to recreate the education systems according to sustainability principles in the foundation to the top [11,23-25]. Although generated momentum has been seen, implementation of green education is faced with significant challenges such as resource limitations, institutional resistance, teacher preparation, evaluation and political opposition. Schools and colleges face the dilemma of meeting the needs of standardized testing and employability capability as well as disciplinary mastery against the cross-cutting, transformative sustainability education. These strains create the need to put in place strategic solutions indicating how green education will be able to improve traditional the education goals and not demoralize them.

Although the green education literature has grown to a significant number, there are a number of key gaps remaining. To begin with, very few longitudinal solutions of the long-term effects of green education interventions on the behavior of learners, their career decisions, and participation are studied. The majority of the researches utilize a short-term pre-post design which leads to the immediate knowledge acquisition and neglects long-term transformational outcomes. Second, there has been a lack of focus on the equity aspects of green education, in terms of the impact of interventions on marginalized communities, learners with disabilities and students in resource-limited settings. Third, the literature is still largely structured around formal education, and poor attempts to show informal education learning situations, the training in the workplace, and lifelong education. Fourth, theoretical frameworks have tended to be based in Western orientations of epistemologies with little incorporation of the indigenous knowledge systems and the non-western based traditions of pedagogy. Fifth, it is not yet explored how effective models of green educational models can be scaled and transferred into other contexts which

may be characterized by different cultures, politics and economies. Sixth, the dynamic technological environment is rapidly developing, which researchers can not keep up with conducting effective studies on the integration of new technologies in green education. Lastly, the interdisciplinary linkages of green education and other areas like urban planning, social innovation, and public health need more theoretical and empirical growth.

The use of this extensive literature review aims at bridging these gaps as follows:

- 1) To integrate the existing theoretical frameworks and pedagogy in green education on environmental, social, and economic levels.
- 2) To establish some major concerns, obstacles and constraints to the wide implementation of the idea of green education.
- 3) To test at the opportunities of growing, relocating, and personalizing innovations of green education.
- 4) To measure evaluation processes and methods of impact measurement of green education.
- 5) To investigate and examine the policy regimes, institutional framework, and governance frameworks that facilitate or limit the green education.

## **2. Methodology**

The PRISMA approach to preferred report items to systematic review and meta-analysis was used as it is a systematic, transparent, and reproducible way of identifying, screening, and analyzing literature of interest based on the available scholarly publications. The literature search concentrated on peer-reviewed journal articles and conference proceedings as well as seminal reports published between January 2019 and December 2024 as primary concerns and focused recent and newly published research that may have a future impact of citation. Several academic databases such as Scopus, Web of Science, ERIC, Google Scholar and specific repositories of sustainability education were used as search strategies. The main search terms were such a combination of green education and the other terms were education and sustainable development, sustainable literacy, environmental education, climate change education, SDG education, transformative learning, ecological literacy, and sustainable development goals. Proximity searches and Boolean operators narrowed the search to get results that covered literature on such situation as environment, social and economic aspects. The preliminary screening revealed 1247 potentially relevant publications, which had been reviewed according to the predetermined inclusion criterion: peer-reviewed publications, the topic concerned educational interventions or frameworks, their application had to be explicitly linked to the sustainability dimensions, and their meaning had to be empirical or theoretical. Such a screening diminished the number of articles to be reviewed in full text to 394. The comprehensive review with stricter quality and relevance promoted led to the eventual selection of 147 publications of high quality in which this review has based. The extraction of the data used a framework to encompass the details of the publications, the theoretical base, methodology of the study, main results, situations of implementation and gaps. Thematic analysis was used to establish recurrent patterns, emerging trends, contradictions, and gaps in the knowledge through the literature. Quality appraisal involved methodological rigor, theoretical basis, depth of contextuality and significance of contributions. Synthesis entailed storytelling about exploring conceptual relationships as well as tabular summaries of organizing practical aspects of green education research and practice.

## **3. Results and discussions**

### *3.1 Theoretical Roughness and Pedagogical Modeling*

The modern green education scholarship is founded on various theoretical traditions which together purpose the holistic approach to sustainability learning [26-28]. The transformative learning theory is a

source of basic knowledge about the way people take a critical look back at and update their worldviews, assumptions, and mental images about the connection between human and nature and sustainability issues. According to this view, disorienting dilemmas, critical reflection, and perspective transformation is a major variable upon which learners gain new consciousnesses on the interdependence of the environment, society, and economy [29-32]. Experience-based learning models place the direct interaction with the ecological system, the community setting, and the sustainability projects as the core element of significant learning [31,33-35]. These strategies appreciate that abstract categories such as sustainability are made body yet actualized in gardens, forests, cities, and localized projects. Place-based education (also known as place-based learning) is a salient method of learning relating learning to local ecological and cultural setting and develops a greater appreciation of particular environmental issues and attachment to particular locales that inspires stewardship practices [36-38]. Systems thinking approach pedagogy helps students cope with the complexity of sustainability challenges by learning how to perceive the interconnectedness, the feedback loop, and emergent properties, and the unintended consequences of behavior in socio-ecological systems. This paradigm leaves the linear cause-effect arguments and feeling in favor of dynamic relations, time scales and cross scale interactions. System literacy allows learners to be able to learn how isolated actions can form systemic consequences and that actions by any system impact the environment, social, and economic systems [1,39-41]. The traditions of critical pedagogy offer an important insight into the power, justice, and change in green education. The methods explore how sports of environmental degradation impact most disadvantaged populations, the ways mainstream discourses veil systems of structural injustice, and the role of education in sustaining or disrupting a system that is unsustainable [42-44]. The environmental justice pedagogy is a particular approach which combines analysis of racism, classism, and colonialism with the issues of the environment, acknowledging that the true sustainability can only be achieved by eliminating the social inequalities [45-46]. Constructivist learning theories guide moderately participatory and learner-oriented learning methodologies in which individuals are engaged in constructing knowledge using social interaction, collaborative inquiry, and co-creation of knowledge. The social constructivism especially bears the stress on the way the understanding of sustainability is influenced by cultural contexts, language, and common meaning-making. These views assist in peer learning, community partnership, and cooperative problem solving as instructional and educational methods. Action competence frameworks concentrate directly on elaborating the ability to engage in individual and community action to sustainability and motivation. Instead of automatic presuming that knowledge simply makes a person behave in a certain way, these methods progressively develop abilities, efficacy beliefs, and significant courses of action. Action competence development entails the critical thinking regarding the sustainability issues, proposing alternative futures, planning, action, planning, and contemplating the actions consequences.

Ecological literacy goes beyond the biological knowledge and includes emotional bonds with nature, ethical values about human-nature associations as well as practical abilities of living sustainably [18,47-49]. This multidimensional literacy combines cognitive level of cognition about its ecological principles, Affective level of appreciation about its beauty and intrinsic worth of nature, and Behavioral competencies to minimize the environmental effects. Creating ecological consciousness that physical space influences educational space itself, biophilic design principles are more and more applied to the education space. Indigenous knowledge systems propose alternative forms of epistemology such as the focus on reciprocity and interrelatedness, the responsibility of generations, and holistic perceptions of the human-nature connections. Combination of traditional ecological knowledge with modern scientific knowledge produces pluralistic strategies to respect dissimilarity of various modes of knowing and answers historical placement of indigenous viewpoints in institutional education. Such paradigms specifically highlight stories, ritual, wisdom of the elders, and learning on the land. Futures thinking and anticipatory competence solve the aspect of the sustainability education that is temporal in nature, and that is the ability of knanners to be able to see the alternative futures and think long term, and discuss the intergenerational consequences. The use of scenario planning, backcasting and speculative designing makes it possible to look at the possibilities of the future and the pathways leading to the wanted results. This futuristic orientation is the complement of historical analysis and problem-solving of the present.

### 3.2 Green Education and Digital Technologies and Innovation.

Green education delivery, accessibility and effectiveness have undergone a massive change, which is brought by digital transformation [50-52]. The learning management systems that are specifically developed to support sustainability education incorporate multimedia information, interactive simulation, a peer collaborative tool, and tracking the progress [53,54]. These platforms allow tailoring learning journeys to the individual level of knowledge, likes and interests in sustainability without compromising on the curriculum integrity and assessments. Applications of artificial intelligence in green education include adaptive learning systems, which modify the difficulty of content and its presentation based on learner performance, intelligent tutoring, which gives one-on-one feedback on sustainability projects, natural language processing, which allows one to talk to environmental databases, and predictive analytics which can be used to identify students who are in danger of becoming unengaged. Machine learning models can be used to analyze complicated datasets of the environment therefore, big data can be used in student research projects and acquiring data literacy and sustainability skills.

The technologies of virtual and augmented reality develop an atmosphere that helps break the geographical and temporal limitations of learning the environment [55-57]. Virtual field trips take students to ecosystems, energy generation sites that are renewable, to sustainable farms, and also climate prone areas around the world. Enhanced outdoor learning with augmented reality can be used to offer contextual information on plants, animals, geological features, and other processes occurring in the environment in real-time. These technologies are especially useful with students who can not be given an opportunity to experience a variety of natural environment or with the exploration of ecosystems that are too distant, too dangerous, or too fragile to visit in any physical form. Gamification can be used in strategies that involve game design principles to sustainability education, in order to enhance the levels of engagement, motivation, and persistence in learning.

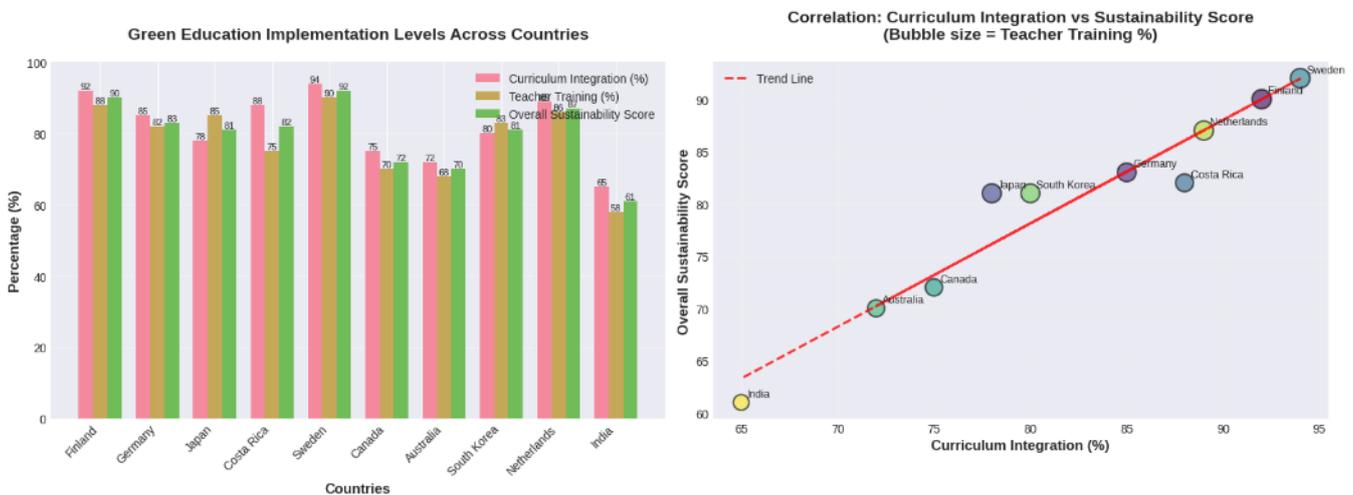


Fig 1: Green Education Implementation Levels Across Countries

Fig. 1 shows the implementation levels of green education across different countries, measuring curriculum integration (0-100%), teacher training (0-100%), and overall sustainability score (0-100). Higher values indicate more comprehensive integration of sustainability principles into national education systems. The serious games are simulations of sophisticated environmental systems, where the learners can experiment with policy interventions, technological advances, and behavioral shifts and see the results of the experiment in the virtual. Rivalry, accomplishment awards, the scorecard, and storyline are the competitive components that ensure the sustenance of interest and impartation of the concepts of sustainability. It has been shown that educational games that are made in a well-executed manner enhance systems thinking, decision-making abilities, and environmental cognition. Citizen science platforms involve learners in real-world research through gathering of environmental data, biodiversity tracking, and climate indicators, among others and the addition of information to the

scientific databases. Online protocols and data visualization interfaces, as well as mobile applications, allow students to be involved in the research networks worldwide. This method builds scientific literacy, skills of using data and the knowledge about the environment and adds value to research that drives conservation efforts and policy changes. Online communities and social media provide an easy way to collaborate on the sustainability projects all over the world, helping students in different continents to see the experiences, compare the situations, and share the outcomes in terms of solving the environmental issues. The digital storytelling platforms enable learners to record sustainability projects and produce multimedia stories that convey the message on the environment to larger audiences. Hashtag campaigns, video challenges, and viral content strategies are strategies that create usage of social media dynamics to provide environmental advocacy and change behavior.

Sensors and monitoring devices can be integrated using the Internet of Things platform to collect real-time data of the environment in educational establishments and neighborhoods. The students design and implement sensors that can measure air quality, energy expenditure, and water usage, temperature, and other sustainability subjects. This practical exposure to the environmental monitoring technologies advances the technical expertise in addition to creating action data towards institutional sustainability enhancements. The blockchain technology is currently being used in the tracking of sustainability credentials with green certifications being verified, carbon credits in educational offset programs being managed, and transparent school procurement supply chains. The applications will expose learners to the latest technologies in addition to showing them how distributed ledger systems can be applied practically in environmental governance. Remote sensing and geographic information systems are some of the most effective ways of initiating the use of spatial analysis of environmental patterns, land use changes, deforestation, urbanization, and impacts of climate. The spatial literacy establishes through the investigation of real-life environmental problems using satellite imagery, drones, and GIS maps in student projects. Such technologies make the use of advanced instruments of environmental analysis accessible to everyone, allowing it to be used by only professionals before. Complex socio-ecological systems, such as the watershed hydrology and climate and also urban energy systems, could be explored using digital modeling and simulation software. Students control variables, experiment and observe results at increased time frames, gaining intuition of the behavior of a system and the impacts of an intervention. Skills of computational thinking, which are a result of modeling, supplement conventional scientific methods of inquiry.

### *3.3 Integrating the Curriculum and Interdisciplinary Approaches.*

The best example of green education is not a single course of environmental studies but rather spreads across a whole curriculum [58,59]. Sustainability in mathematics education is involved in statistical analysis of climatic data, resource allocation optimization problems, geometric designs of energy-saving structures, and renewable energy investments money modelling [3,60-61]. With these applications, mathematical relevance is made and quantitative sustainability literacy is built. In language arts integration, there are environmental literature reading and writing persuasive essays on environmental issues, analyzing the media coverage of climate change, creating environmental poetry and narratives, developing environmental advocacy communication skills. Literacy competencies enhance further by working with the contexts of meaningful sustainability and literary analysis helps make known how the language merits and creates environmental knowledge and values. The sphere of social studies inherently embraces the concept of sustainability by analyzing the environmental historicity, environmental justice activism, urban green planning, environmental policy, and the comparative study of cultural approaches to human-nature relationships. Historical approaches show us the way past communities have done well or poorly in resource management giving us warning lessons and positive examples. Civics education discusses the methods of decision-making on environmental matters by democracy and rights and duties of learners living in an environment as good citizens.

In education Science education is returning to a more comprehensive framework of earth systems that looks at biogeochemical processes, energy flows, climate, and human impacts on a larger scale. Scientific practices are formed through query-based investigations of the local environment issues, as opposed to building environmental stewardship. Green chemistry, renewable energy technologies as

well as sustainable materials are the areas of interest in more laboratory experiments. The arts education has a very specific contribution to green education in terms of environmental aesthetics, eco-art installations to create awareness about sustainability concerns, biomimicry in design, sustainable choice of materials and artistic representation of relationships between humans and nature. Imaginative facets of the creative processes build imagination needed in picturing meaningful sustainable futures and arts-based communication targets audiences which are less receptive to the message that they used in science.

Education in technology and engineering Incorporates sustainability Technology education Technology education now includes design challenges that tackle actual environmental issues, product life cycle, design of renewable energy systems, sustainable agricultural technologies, and circular economy innovations. Engineering education Examples include design challenges, design challenges, and design challenges involving real environmental problems, product life cycle, design of renewable energy systems, sustainable agricultural technologies, and circular economy innovations. Such areas of learning in project-based learning inculcate technical skills as well as awareness of environmental concerns and entrepreneurial intelligence towards green innovations. The sub themes of physical education and health have incorporated sustainability as people interact with nature in the outdoors, education on nutrition, sustainable food production, active transport that fosters walking and cycling, and how the environment relates to human health. Having mind-body practices such as outdoor yoga and forest bathing is a combination of wellness and connection to nature. The study of business and economics touches more and more upon sustainability in so-called Circular economy models, Triple bottom line accounting, Sustainable supply chain management, green marketing, Corporate social responsibility, as well as critical analysis of economic growth paradigms. The case studies of the successful sustainable businesses and social entrepreneurship help students imagine the paths of sustainability that would be economically viable. The approaches that are whole-school based make certain such disciplinary integrations in a way that is sustainable in the sense of school missions being sustainability-oriented, the operation of the campuses being environmentally friendly, the governance system of the school structures being democratic and the community partnership aspects. Schools per se are turned into living laboratories, where students are exposed to and put into practice institutional sustainability, which generates congruency between the content of the curriculum and organizational activity.

### *3.4 Community Partnerships and Community-Based interventions.*

The Community-based green education is game to the realization that learning sustainability does not only take place within classroom settings but also through families, neighborhoods and even extended civic places [62-64]. Service-learning initiatives have a linking role between academic education and community requirements, including the restoration of habitat, building community gardens, environmental surveillance, and sustainability training of younger students [19,65-67]. These experiences build civic abilities, social resources and environmental responsibility besides offering visible community advantages. Intergenerational learning projects combine youth, adults and elders in community projects of sustainability which exchange their knowledge, generation viewpoints, and community resilience [68-70]. The youth bring technological expertise and creativity of thinking and the adults their resources and institutional accessibility and old people their historical knowledge and long-term visions [71-73]. This two-way learning arrangement subverts the age-level hierarchies and builds on sustainability knowledge. School-community partnerships are characterized by ongoing contacting of both educational institutions and the communities through various organizations such as the environmental nonprofits, municipal sustainability offices, businesses that undertake green practices, cultural institutions, and faith communities. With such collaborations, students get real learning, mentoring, resources, and avenues of student taking action other than the academic needs. Participatory action research is another form of research in which students and community members can be involved as co-researchers exploring sustainability issues in the local areas and enacting evidence based solutions. This practice democratizes knowledge creation, is a capacity enhancer in research among local communities and makes sure that the implications of research are immediately actionable. Participatory action research which is led by the youth especially gives the youth the capacity to be valid knowledge producers and change agent. Families and guardians are considered the vital partners

when it comes to sustainability education by family engagement strategies. Family sustainability issues, house energy surveys, zero-waste campaigns, and parent education classes bring learning to the households, and even recognize that family practices have significant influences on children environmental behaviors and values. The cultural responsiveness approaches respect the different family systems, values, and sustainability activities.

Community-based social marketing utilizes the behavioral science knowledge to help promote sustainable behaviors by the community using community-level interventions consisting of education and structural supports like infrastructure improvements, incentives programs, social norms campaign, and elimination of obstacles to sustainable decisions [50,74-76]. The participation of the students in the design and implementation of these campaigns shapes the skills of marketing besides contributing to the sustainability transition in the community. Through environmental volunteering programs, students are put in contact with environmental protection organizations, urban agricultural ventures, recycling campaigns and environmental lobbyists. Practical skills developed through regular involvement of volunteers, long term commitment, peer communities formed around the sustainability principle, and offering a career route into the environmental employment. It is value through recognition and celebration of the contribution of the volunteers to instil positive identities as the custodians of the environment. The Community resilience building is a way that involves social aspect of sustainability as it enhances community capability to recover and adapt to environmental changes. Projects by students to capture local knowledge, mapping of the local assets, emergency preparedness planning and community support networks add to resilience in the process of understanding the social facets of sustainability. The policy engagement exposes students to the other processes of environmental governance by participating in the public hearings, communicating with the elected authorities, testifying in the policy concerning environmental issues, and youth advisory councils. Through these experiences, there is demystification of the political processes, advocacy skills are developed and youth voice is demonstrated in decisions regarding the environment. The civics education becomes more realistic when related to actual policy process involving student communities.

### *3.5 Evaluation and Performance Measurement.*

Green education evaluation is a special challenge due to the long-term, multidimensional and transformative prefiguration of the desired results [77-79]. The Traditional knowledge tests are able to represent cognitive knowledge of the environmental concepts however they do not measure the deeper learning such as values, dispositions, skills, and behavioral intentions. Rigorous evaluation systems adopt several approaches that seek to cover different aspects of competence of sustainability.

Fig. 2 tracks the progression of student environmental knowledge scores (0-100), pro-environmental behavior index (0-10), and climate anxiety levels (1-5 scale) over a 24-month intervention period. The data demonstrates how sustained green education impacts both cognitive understanding and behavioral outcomes. In performance-based assessment, students are tested in the context of implementing sustainability knowledge in real-life activities like environmental audit, planning of sustainable solution to a real life issue, organizing workshops, developing policy proposals, and producing environmental communications products. The rubrics of such assessments are both process- and product-based and appreciate creativity, collaboration, critical thinking, and practicality of the real world not just technical accuracy. Portfolio assessment is the compilation of evidence of learning over long durations in the form of reflective journals, documentation of project, and photographic documentation of activities that have been performed, artifacts produced, and testimonials of partners in the community. Portfolios disclose the growth patterns, the personal involvement, and the personal change which is lacking in snapshot evaluation. Digital portfolios help researchers document using multimedia and provide continuous feedback on portfolio research by teachers, peers, and external mentors. Peer assessment and self-assessment form shared responsibility of learning and metacognitive skills. Students will engage in self-reflection by developing their sustainability knowledge, skills, values, and behaviors and giving positive criticism to colleagues. By such processes critical self-consciousness, and cooperative skills are formed necessary towards taking a joint action on sustainability issues. The ecological footprint tracking and behavioral observation give actual inputs on the sustainability related behaviors.

Educational interventions are measured by schools in terms of energy consumption, waste generation, water usage, mode of transportation and food waste. Personal sustainability tracking uses allow them to track and analyze their resource use on their own and to bridge the gap between abstract ideas and physical behaviors.

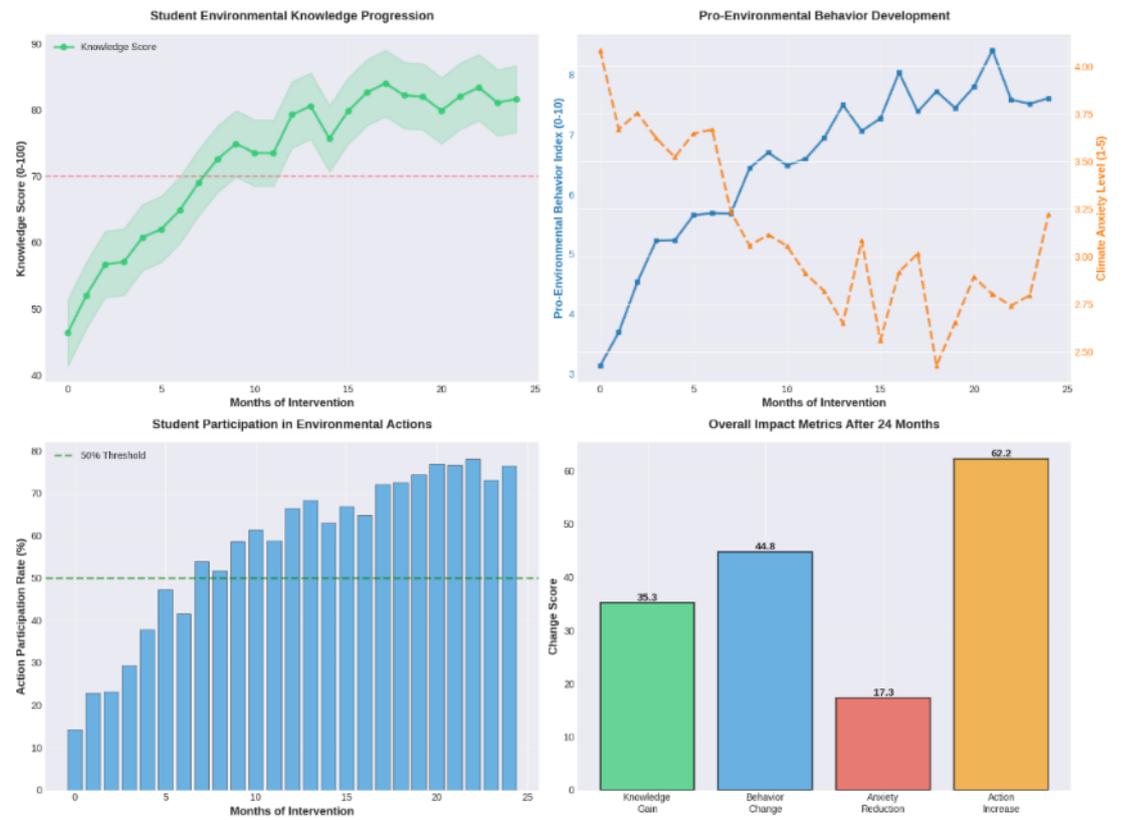


Fig 2: Student Environmental Knowledge and Behavior Change Over Time

Table 1: Green Education Pedagogical Approaches and Implementation Strategies

Sr. No.	Pedagogical Approach	Key Techniques	Implementation Tools	Target Outcomes	Challenges	Opportunities
1	Transformative Learning	Critical reflection, perspective transformation, disorienting dilemmas, dialogue	Reflective journals, Socratic seminars, case studies, challenging assumptions	Worldview shifts, values examination, behavioral change	Discomfort with challenging beliefs, time intensity, assessment difficulty	Deep personal transformation, sustained commitment, leadership development
2	Experiential Learning	Direct engagement, hands-on activities, field studies, learning by doing	Gardens, field trips, outdoor classrooms, community projects	Embodied understanding, skill development, nature connection	Resource requirements, safety concerns, weather dependency	Memorable learning, multisensory engagement, practical competencies
3	Place-Based Education	Local ecological and cultural investigation, community partnerships, bioregional focus	Watershed studies, local history projects, elder interviews, neighborhood assessments	Deep place attachment, local knowledge, community connection	Limited generalizability, requires extensive local knowledge, community access	Relevance to students' lives, culturally responsive, actionable learning
4	Systems Thinking	Interconnection identification, feedback loops, emergence, scale thinking	Concept mapping, system dynamics modeling, case studies of complex issues	Pattern recognition, complexity appreciation, unintended consequence anticipation	Abstraction difficulty, overwhelming complexity, assessment challenges	Sophisticated understanding, transferable thinking skills, policy relevance
5	Critical Pedagogy	Power analysis, justice	Social justice frameworks,	Critical consciousness,	Political controversy,	Social transformation

		examination, structural critique, transformative action	environmental justice case studies, participatory action research	equity commitment, structural analysis capacity	institutional resistance, emotional intensity	potential, empowerment, equity advancement
6	Project-Based Learning	Extended investigation, authentic products, student voice and choice, public presentation	Design challenges, research projects, community problem-solving, exhibitions	Deep knowledge, collaboration skills, real-world application	Assessment complexity, time demands, uneven student contribution	Student motivation, authentic achievement, visible impact
7	Inquiry-Based Learning	Question generation, investigation design, evidence evaluation, conclusion drawing	Scientific method, field research, laboratory experiments, surveys	Scientific literacy, research skills, evidence-based reasoning	Requires scaffolding, time intensive, uncertain outcomes	Student ownership, curiosity development, authentic science practice
8	Collaborative Learning	Peer interaction, group investigation, shared knowledge construction, collective action	Jigsaw activities, team projects, peer teaching, collaborative problem-solving	Teamwork skills, diverse perspective appreciation, social learning	Free-rider problems, conflict management, logistics complexity	Social support, enhanced learning through teaching, collective efficacy
9	Service Learning	Academic learning, community service, structured reflection, reciprocity	Habitat restoration, environmental education for others, community environmental audits	Civic skills, social responsibility, meaningful contribution	Logistics complexity, ensuring reciprocity, time requirements	Community impact, student satisfaction, skill application
10	Indigenous Pedagogies	Storytelling, ceremony, land-based learning, relational accountability, holistic engagement	Elder mentorship, traditional ecological knowledge sharing, cultural protocols, seasonal rounds	Cultural knowledge, alternative epistemologies, respectful relationships	Cultural appropriation risk, requires indigenous leadership, protocol navigation	Epistemological diversity, decolonization, deeper ecological understanding
11	Digital Learning	Online platforms, virtual reality, gamification, AI personalization, citizen science apps	Learning management systems, VR headsets, educational games, mobile applications	Technological literacy, accessibility, personalized pacing	Digital divide, screen time concerns, technology costs	Scale possibilities, geographic barriers reduced, data access
12	Arts Integration	Visual arts, music, theater, creative writing, design thinking	Eco-art projects, environmental theater, creative writing, multimedia production	Creativity, emotional engagement, alternative expression modes	Perceived frivolity, assessment challenges, requires arts skills	Reaching different learners, public engagement, imaginative capacity
13	Outdoor Education	Nature immersion, adventure activities, wilderness experiences, outdoor skills	Camping trips, wilderness courses, forest schools, outdoor leadership programs	Nature connection, risk-taking, resilience, environmental appreciation	Safety concerns, liability, cost, accessibility barriers	Powerful experiences, mental health benefits, transformative potential
14	Gamification	Points, badges, leaderboards, challenges, narratives, competition and collaboration	Sustainability challenges, educational games, simulation software, mobile apps	Engagement, motivation, systems understanding through play	Superficial engagement risk, competitive stress, game design complexity	Student motivation, safe experimentation, immediate feedback
15	Action Competence Development	Skills building, efficacy cultivation, action opportunities, reflection on action	Action projects, advocacy campaigns, student environmental governance	Agency, self-efficacy, practical skills, democratic participation	Action without critical reflection, tokenism risk, institutional barriers	Empowerment, visible impact, leadership development
16	Futures Thinking	Scenario exploration, backcasting, visioning, speculative design, long-term thinking	Future workshops, scenario planning exercises, science fiction analysis, time travel activities	Anticipatory capacity, hope, long-term perspective, strategic thinking	Uncertainty anxiety, overwhelming complexity, difficulty imagining alternatives	Creative possibility exploration, hope cultivation, strategic capacity

17	Contemplative Practices	Mindfulness, nature meditation, reflective silence, embodied awareness	Forest bathing, sit spots, journaling in nature, mindful walking	Present-moment awareness, stress reduction, deep observation, inner stillness	Perceived religious connotations, discomfort with silence, time constraints	Mental health benefits, enhanced observation, inner resources development
18	Participatory Action Research	Student researchers, community co-investigation, action orientation, knowledge democratization	Youth-led research, community-based participatory research, photo voice, surveys	Research skills, community partnership, action outcomes, knowledge production	Methodological rigor concerns, power dynamics, time intensity	Student empowerment, community impact, authentic research experience
19	Comparative Cultural Approaches	Cross-cultural examination, diverse knowledge systems, international partnerships	International exchanges, comparative case studies, multicultural literature, virtual partnerships	Cultural competence, perspective-taking, global citizenship	Stereotyping risk, superficial engagement, language barriers	Global awareness, appreciation of diversity, collaborative possibilities
20	Interdisciplinary Integration	Subject connection, thematic units, team teaching, breaking disciplinary silos	Integrated units, co-taught courses, school-wide themes, project-based units	Holistic understanding, knowledge transfer, real-world relevance	Scheduling constraints, teacher preparation demands, assessment complexity	Coherent learning, efficiency, authentic knowledge application
21	Emotional Learning	Emotion recognition and processing, climate anxiety support, hope cultivation	Emotional check-ins, therapeutic supports, peer support groups, hope-building activities	Emotional intelligence, resilience, psychological wellbeing, sustained engagement	Requires psychological safety, teacher emotional capacity, varying student needs	Wellbeing support, authentic engagement, sustainable commitment
22	Democratic Participation	Student voice, shared governance, participatory decision-making, rights and responsibilities	Student environmental committees, participatory budgeting, youth advisory councils	Civic skills, agency, institutional improvement, democratic values	Power-sharing resistance, time demands, logistical complexity	Student empowerment, better decisions, ownership and accountability
23	Career Exploration	Green job investigation, mentorship, internships, career pathway planning	Job shadowing, informational interviews, internships, career fairs, alumni panels	Career awareness, skill development, professional networks, employability	Placement logistics, liability concerns, limited opportunities in some regions	Employment pathways, student motivation, professional development
24	Whole-School Approaches	Institutional coherence, facilities management, governance, community role	Green building features, sustainable operations, environmental policies, community partnerships	Institutional transformation, coherent messages, visible commitment	Resource demands, stakeholder coordination, institutional inertia	Comprehensive impact, learning laboratory, community leadership
25	Assessment Innovation	Performance tasks, portfolios, self-assessment, long-term tracking, multiple methods	Rubrics, portfolios, exhibitions, reflection protocols, behavior tracking, surveys	Valid assessment of complex competencies, formative feedback, student ownership	Development time, scoring complexity, comparability concerns	Meaningful assessment, learning orientation, comprehensive evidence

Environmental attitudes, environmental values, connectedness to nature, and sustainability efficacy beliefs measured are determined using attitudinal surveys using validated scales. Pre-post designs can be used to determine the achievement of attitudinal changes that can be attributed to educational interventions although the longitudinal can be used to determine the long term development of attitudinal changes [80-82]. Focus groups and qualitative interviews are suitable to the surveys as they demonstrate subtle knowledge, inconsistencies, and contextual influences to attitudes. System thinking tests determine the ability of learners to perceive interconnections, find feedback loops, think of the unintended consequences and scale/time cross-boundaries [20,83-86]. The tasks of concept mapping, causal loop diagram and scenario analysis give an understanding of systems. The models worked out

by students would, to an extent, demonstrate the complexity in depicting the complex socio-ecological relationships. Action competency frameworks do not only evaluate the knowledge and attitudes, but also skills, efficacy, and getting involved in sustainability behaviours. Measurement instruments determine the level of confidence that students have to act, the level of participation that students actually assume when it comes to individual and group actions, and perceptions by students about actually not doing anything about it. To determine the connection as well as the relationship between knowledge, attitudes and behavior it is necessary to specifically evaluate each dimension. Long-term follow-up studies can look on intervening effects of education that may occur years after the completion date of the education and they evaluate the ability of green education to affect career choices, civic participation, lifestyles and continued learning years after official interventions. Although long studies are difficult and consume resources, they best present long-term transformation instead of temporary impact. Long-term outcomes are seen in alumni surveys, career pathway analysis and case studies of sustained engagement.

Community level level impact assessment looks at more general impact of a green education such as institutional policy modification, community sustainability developments as a result of school projects, and community discourse change as a result of school projects, and quantifiable environmental gains [87-89]. Change theory models follow hypothetical lines of educational contributions to the middle-range results to the final communal and environment effects.

### *3.6 Preparation and Professional development of teachers.*

The key to effective green education lies in teachers having environmental knowledge as well as having pedagogical, systems thinking, participating learning facilitation, and personal devotion to the sustainability [3,90-92]. Preteacher education tends to be more and more comprehensive in introducing the concept of sustainability to pre-service teachers, as opposed to making it the specialty of science teachers. Teacher candidates undergo transformative learning methods that will be taken to facilitate later, learning content knowledge and pedagogical content knowledge of sustainability education. Teacher sustainability literacy involves dimensional levels of environmental science, social justice, economic systems and teaching policies. Professional development initiatives are used to fill knowledge gaps in teachers by using intensive institutes, professional learning communities, online course-based and mentorship programs that link less experienced teachers to sustainability education leaders. Professional development is effective when it involves active learning, collective investigation and practice as opposed to the issue of passive transmission of information. The development of pedagogical skills is concerned with the facilitation strategies to enable inquiry-based learning being, student-centered which will put the teachers in the role of guides and co-learners instead of knowledge experts. In project-based learning, place-based education, collaborative learning structures, facilitation of reflective practice, and participatory action research, teachers gain competence in learning. Models are used to develop the skills during modeling, rehearsal with feedback, observation by others and through repetition. Place-based professional development places teachers within the local ecosystems, community-based sustainability projects as well as collaborating with environmental groups. The first one is direct experience of local environmental and social environments as that way, teachers can create a real place-based curriculum relating abstract sustainability ideas with the world in which students live. Place-based learning also develops personal relationships of teachers with both natural and community environment that add value to teaching.

Professional learning communities establish professional communities that provide sustained support to collaborate on curriculum development, ensure teaching methods, commenting on student work, discussing difficulties in implementation, and improving practices [8,12,93-95]. These communities decrease seclusion, upkeep innovation as well as establish shared expertise. Online communities allow teachers in any part of the world to collaborate even though the collaborative work is on sustainability education. Action research involves teachers as researchers who probe into their practice, experiment with innovations in the pedagogue and make contributions to the body of knowledge about effective sustainability education. Action research by teachers enhances the reflective practice, evidenced-based betterment, and agency of the professionals and creates context-based findings supplementing scholarly

research. Publication and presentation of findings of action research through conferences helps to develop professional identities of teachers as producers of knowledge. The training of the leader educates teacher leaders to lead sustainability education in their school, support collegial professional growth, organize sustainability programs at schools, and advocate schools in the community relations. Leadership on the part of teachers becomes a key to the institutional change and the implementation that is long lasting and cannot be maintained only within the classrooms. Interdisciplinary collaboration competencies empower the teachers in intersubject area work, co-plan integrated units, and organize the entire-school strategies. The process of professional development that establishes scheduled periods and procedures of joint planning develops the capability and desire of teachers to cross-disciplinary boundaries. Efficient models involve teams of teachers who share a group of students, planning time together, and administrative backing on the development of the curriculum. The attention on self care and resilience is increasing in efforts to address disturbing facts of environmental degradation and social injustice as a constituent of sustainability education. The teachers need processing climate anxiety skills, the ability to maintain hope when faced with overwhelming circumstances, burnout prevention, and demonstrating healthy responses upon receiving distressing information. Teacher wellbeing is a development that is needed to continue working without becoming overly engaged with the hard curriculum.

### *3.7 Policy Frameworks and Institutional Governance*

Sustainability education is being made mandatory at the national education policies, albeit with differences in outcomes of specificity, implementation and accountability [96,97]. Those countries with the best implementation usually incorporate sustainability in their product across the curriculum standards, requirements of teacher certification, school performance metrics, and education funding formulae. Coherence of policies in these dimensions is more practical as compared to standalone mandate without supporting infrastructure. The global guidelines are offered by international frameworks such as Education for Sustainable Development program by UNESCO, the UN Decade of Education for Sustainable Development, and SDG Target 4.7, but they leave the national and local contextualization. These models create unified values and objectives and admit various channels that are fitting different cultural, economic, and environmental settings. The international networks enable the knowledge sharing and reciprocal learning of countries at different levels of development on the field of sustainability education. Sustainability are being integrated in the accreditation relating to educational facilities in terms of the content of the curriculum, operations of the campus, the form of government, the relationship with the community, student achievements. Sustainability oriented accreditation offers institutional motivation and responsibility towards green education as well as offering provisions of systematic evaluation and amelioration. The third party verification strengthens the credibility and comparability among the institutions. Some direct funding streams that favor green education are competitive grants to support innovative programs, formula grant that acknowledges sustainability education in the per-pupil grants, investment in green school infrastructure and professional development grants. Specific sources of funds remain indications of priorities in policy and procure funds that are targeted to facilitate the quality. Nevertheless, sustainability should not merely move into fringe education thus extending its tentacles into mainstream education financing systems instead of relying on some special financing that is subject to change along with political wills. Board policies in schools and district-wide commitment offer local structures of governance that allow and compel sustainability education. Effective district policies provide effective expectations and resource distribution, professional growth, coordination formations, and execution supervision. The leadership of the school boards is especially important in the cases when there are no firm policies on a national or a state level. Whole-institution strategies entrench sustainability within their organizational operations, purchasing policies, energy and water operations, waste management, food services, modes of transportation and landscape management. Schools who walk what they talk it all leads to coherence between curriculum and operations that the students experience. Green school facilities are demonstrators of sustainable technologies and practices by what they represent in their living laboratory.

The collective decision making by youth in the case of institutional governance will make youths masters of their learning proceeds as they will concern themselves with the sustainability challenges

[23,98-99]. Participatory budgeting of environmental projects, participation in the sustainability committees by a student representative, leadership of the environmental audit by students, and environmental advisory groups composed of youth are good examples of meaningful rights of participation. Civic skills are built with youth governance participation since they enhance the quality of the decisions made with consideration of the student views. Partnership policies are designed to establish structures on long term partnership between schools, university, community organizations, business, government and indigenous communities. Partnerships are codified by memoranda of understanding, joint appointments, resource sharing agreements and coordinated programming which are sustainable and mutually beneficial. Partnerships thrive thanks to policy facilitation and support such as liability protection and recognition schemes and resources. Quality standards and guidelines offer standards of superior sustainability education that covers the scope and sequence of the curriculum, pedagogy, assessment, teaching, learning, qualifications of teachers, and community involvement, and practices in the institution. Standards increase the direction of the program development as they make it possible to guarantee quality. Yet, too prescriptive norms can limit creativity and localization, and moderated measures are needed to provide clarity of standards and respect localization.

### *3.8 Equity, Inclusion, and Cultural Responsiveness.*

The views of environmental justice demonstrate how vulnerable populations end up as the most affected groups in relation to environmental risks such as pollution, climatic effects, and lack of resources in comparison to the minimal understanding of environmental policies and practices [100-102]. Green education dealing with equity investigates such inequalities as well as examines historical, structural and structural movements in the source of environmental injustices and builds on the ability of students to promote equitable environmental policies and practices. The case studies on the environmental justice struggles show that communities organize to effect change and reflect intersections of race, class, colonization and environmental struggles. Cultural responsiveness of green education celebrates the variety of relationships to nature, ecological wisdom, spiritual bonds to land as well as culturally distinctive sustainability. In place of projecting environmental values that are dominant cultural, culturally responsive presents an opportunity to students to understand their own cultural heritages in terms of environmental stewardship, use the wisdom of their elders, and learn how various cultures conceive human-nature relations. Curriculum contents, instructional examples, and the role models of the environment need to be represented in a diversity to guarantee that everyone has an opportunity to recognize themselves. The language access is vital towards fair green education, where multilingual resources, interpretation, and awareness of environmental notions may be culturally entrenched and unable to be directly translated. The concept of bilingual and multilingual is a means of appreciating linguistic diversity at the same time as making the message understood. A combination of teaching environmental words in home languages and majority language is a process that develops conceptual knowledge of students and respects language traditions. The principles of universal design of learning allow the students to access green education despite their varying learning requirements such as disability, various learning styles, different prior knowledge, and multiple intelligences. There are several sources of representation that offer information in different forms, several sources of action and expression that allow different forms of showing knowledge, and several sources of engagement that provide an option of intrinsically motivating. The outdoor learning areas, field trips and practical activities must be designed in a way that enables all students to participate in attaining the full potential of outdoor learning as long as they are mobile, have sensory or any other disability.

Along with socioeconomic status such as field trip prices, field trip equipment, project materials and time commitments disadvantage low-income group students [88,103-105]. Schools manage these obstacles by subsidizing it, offering equipment on loan schemes, in-school project options and alliances offering facilities [106-109]. To prevent making assumptions concerning the availability of resources at home and the capacity of the family, it would be critical to include practice. Gender considerations appreciate the fact that environmental concerns concern individuals unequally, according to their gender as the traditional approaches to environmental education focused on the male vision and omitted the female input. Green education which is gender responsive gives emphasis to women environmental

leaders, gender aspects of environmental effects and roles, dispels the stereotypes of outdoor activities and careers in the environment and provides safe, welcoming learning conditions to all gender orientations. Secular does not adequately focus on religious and spiritual aspects of sustainability even though they greatly impact on the values and actions regarding the environment. Inclusive green education enquires approvingly how various religious and spiritual customizations encounter the duty of people toward creation, unite admiration to nature with environmental oversight, and inspire sustainable practices by religious or spiritual values. Separation of state and religion should not mean academic investigation of religious environmental point of view. Urban-rural permeabilities form the environment experience and views where urban students tend not to access nature as compared to knowledge on nature by rural students whereas those in urban sustainability issues may lack experience in the rural environment. Good green education is one that covers both the urban and the rural situation, which enables the interchange of urban and rural students and the impacts of urbanization to its urban populations as well as to the rural world. Rural people being stereotyped as the environmentally backward or urban citizens as alien to nature need to be challenged. The field of representation in the environmental sphere is still biased against the privileged groups, which poses a challenge to the diverse students who aspire to an environmental career. Environmental careers are more accessible to students who are exposed to various environmental professionals, mentorship programs, matching the students with role models and having an explicit discussion of barriers and pathways. Collaboration with institutions that are principally administered by and serving the underserved communities offer genuine counter-examples of varying environmental leadership model forms.

### *3.9 Climate Change Education*

Climate change education has become the main priority of green education due to the existential risk of the anthropogenic climate disruption and the urgency of the shift to the low-carbon societies [6,110-112]. A successful climate education is one that matches the scientific knowledge of climate systems, climate causes, and climate impacts with the emotional processing of anxiety and grief, critical assessment on the social and political levels and agency and hope building by providing meaningful acting opportunities. The knowledge of climate science literacy entails the knowledge of the mechanisms of greenhouse effects, evidence of anthropogenic climatic change, dynamics of climate system, tipping points and feedback loops, impact of climate, and uncertainty of climate predictions in the region and the entire world. The scientific understanding is constructed by real life experiments, interpretation of historical temperatures and carbon records, climate modeling actions and analysis of proxy indicators. To combat climate denialism, students should be armed with skills on how to critically judge information sources, problematic factors of misinformation and scientific consensus processes. Climate educational review looks at the effects on the ecosystem, species, agriculture, water resources, human health, economic structures, and social balance. It is crucial because the effects of climate are extremely different based on geography, and it is necessary to comprehend local weaknesses. The developing countries feel the impact more than the indigenous people, yet with little contribution to the emission of greenhouse gases giving serious cause of concern into the issue of justice. The world has both climate solutions that include mitigation measures to reduce emissions, and adaptation measures that seek to make the world resilient in terms of changes that are inevitable. Education discusses the technological remedies as renewable energy, energy efficiency, sustainable transporting, and carbon sequestration along with behavioral alterations as well as policy interventions and systemic transformations. The proposed solutions are critically analysed to look at tradeoffs, rebound effect, equity implications and feasibility. Climate solution design and implementation system develops student projects, which create systems thinking and innovation capacity.

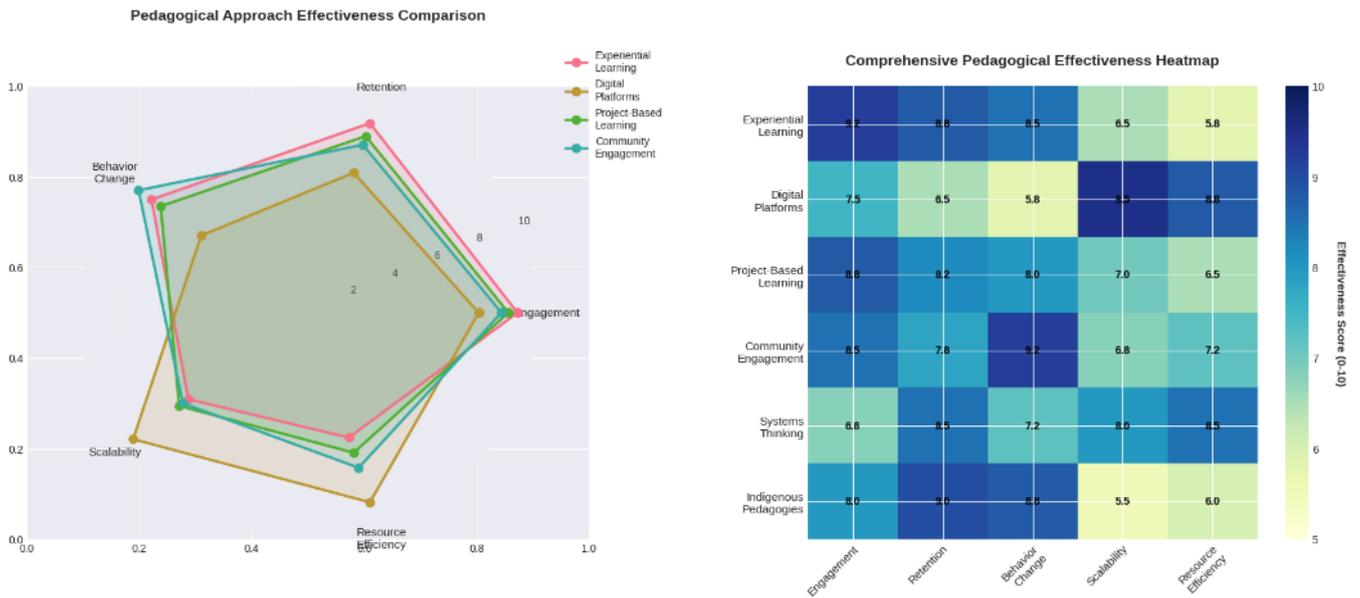


Fig 3: Pedagogical Approach Effectiveness Comparison

Fig. 3 compare the effectiveness of different pedagogical approaches across five key dimensions: student engagement (0-10), knowledge retention (0-10), behavior change (0-10), scalability (0-10), and resource efficiency (0-10). This helps educators choose appropriate methods for their specific contexts. Climate emotions such as anxiety, grief, anger, and fear are explicitly addressed because it is understood that climate change challenges a learner with the truly scary information concerning its future. Eco-anxiety is experienced by large groups of the youth and should not be disclaimed but be proven. There are emotional processing strategies that comprise guided conversations in a secure environment, nature to mitigate stress, art, extreme anxiety therapeutic materials, and investing emotions in productive activity. Climate justice models scrutinize the manner in which the impact of climate change is unjust to those marginalized, the historical emissions of the developed nations afflict the developing countries, and how the frontline communities can be leaders in spite of their minimal contributions to the crisis, and how climate solutions would either propagate or alleviate social imbalances. Intersectional analysis will show that climate vulnerabilities are exacerbated by other kinds of marginalization. Climate justice education establishes solidarity with the impacted groups and their resolve to be in line with equitable solutions. Competence development of climate action goes beyond knowledge to the development of skills, efficacy, and opportunities of effective engagement. The lifestyle choices of individuals such as diet, transportation decisions, and consumer habits do offer points of entry but need to be supplemented by group action that is targeting systematic causes of emissions. Activism among students such as strikes, advocacy, legal actions and youth conferences indicates the agency of the young people and is becoming more a part of policy conversations. Intergenerational aspects are explicitly addressed because the current students will continue to suffer climate effects more in their lives yet they had no contribution in the issue of climate change. This injustice of time arouses justified anger and acts as a stimulus. Conversation with mature generations on the subject of climate accountability, unsuccessful action and joint remedies is worthwhile regardless of the circumstantial challenges. Future orientation and scenario planning allow exploration of other possible futures of climate which could involve catastrophic warming or successful changes to sustainable societies. Looking back to where one wants to go assists in determining the paths and activities required. Climate fiction and speculative design have to work with imagination and invent new societies in a transformed future. Hope should be based on the realistic assessment of challenges and evidence of transformative change as being still possible.

### 3.10 Green Entrepreneurship and Economic Education

Green entrepreneurship education instills knowledge, skills and dispositions of establishment of economic viable ventures in response to environmental and social challenges [113-116]. The trend will link sustainability education to economic literate and business competent and introduce students as the

future entrepreneurs instead of consumers or workers [117,118]. The social entrepreneurship models focus on the projects that generate social and environmental value in addition to financial profits, a question that poses a challenge to businesses that aim at making only profits. The principles of the circular economy offer an alternative to linear take-make-dispose economies and focus on closed-loop economies, the absence of waste, regenerating resources, designing products to last long, and designing systems in an integrated way. Students provide the analysis of material flows, design products to be disassembled and remanufactured, learn about the sharing economy models and investigate industrial symbiosis whereby the waste of a certain industry is the raw material of another industry. Perspectives of systems and design thinking, which apply across sectors, emerge due to circular economy thinking. Sustainable business model innovation is the study of how the businesses generate, provide, and benefit the value and produce positive environmental and social impacts. Examples of successful sustainable enterprises in various sectors can be used as an example and an inspiration. The students examine the concept of tradeoffs, determine the success factors and investigate the effect of market mechanisms, regulation and consumer preferences on business sustainability. Another important issue considered by critical examination is greenwashing, corporate responsibility, and institutional hindrances toward sustainable business. Green job skills are getting a focus with the increasing employment within the renewable energy, energy conservation, sustainable agriculture, environmental, green building and other fields that are environmentally sustainable. These areas enhance access because of career exploration, internship, mentorship and technical skill development. The analysis of the labor market will also make students realize about the tendencies of employment and required qualification as well as challenge the idea about environmentalism in opposition to the economic prosperity.

Sustainability financial literacy consists of knowledge such as green investment vehicles, community development finance, impact investment, crowdfunding social entrepreneurs, and the environmental impactedness of personal financial choices [88,119-121]. Students get to know how to analyze sustainability claims in their financial products, how divestment campaigns affect the behavior of corporations, and more generally how alternative currencies and economic exchange systems can be designed with the focus on the social and environmental values. Critical economic literacy questions mainstream economic growth paradigms, including the use of externalities, limits to growth, alternative sources of well-being to GDP, steady state economics and views on degrowth. Students examine how the traditional economic measures overlook the environmental destruction and the welfare of the society and reinforce unsustainable consumption. Other schools of thought such as the solidarity economy, the commons-based economies and the Buddhist economics offer alternative understandings of the roles of economies. The value chain analysis follows the path of a product extracted on raw material all the way to consumption and disposition revealing all the environmental and social consequences of the process. They ask students to research supply chains of common products, hotspots that create environmental and social harm, seek the mechanisms of transparency, and how consumer demand, regulation, and corporate policy can affect supply chain sustainability. Critical consumption literacy is built up by this systems approach. The pricing externalities and along with the understanding of the true cost accounting clearly shows the existence of environmental and social costs that are usually not reflected in prices. Students estimate environmental costs of manufactured goods, analyze such mechanisms as carbon prices and pollution taxes and discuss the most effective ways of internalizing externalities. Knowledge of why the present cost does not portray the real cost of the subject makes one question the affordability and economic efficiency of unsustainable variants. Alternatives to individual ownership are indicated by the models of collaborative consumption and sharing economy such as tool libraries, car sharing, collaborative housing, and time banks. Students consider how absolute access drops the incidence of resource consumption and has the potential to increase the quality of life. Another perspective, which is closely related to critical analysis, is that certain sharing economy platforms comply with the interests of investors rather than with societal ones, and governance and business models should be designed carefully.

### *3.11 Food Systems and Agricultural Education.*

Food systems education incorporates environmental, social, economic, health and cultural aspects of food production, distribution and consumption [122-124]. When one realizes that food systems are key contributors of greenhouse gas emissions, loss of biodiversity, water depletion, and pollution, and thus provides a place of leverage points to the sustainability transitions, one is likely to think food is central not peripheral to green education. School gardens also offer real-world learning laboratories in which students develop and train their ability to grow food, monitor ecological processes, test sustainable methods of growing food, and gain physical skills and relationships with food. The garden-based learning incorporates science, mathematics, social studies, language arts, as well as arts education as well as cultivating nutritional awareness and inclination to healthy foods. Gardens also establish a community meeting grounds, therapeutic spaces and place of intergenerational interaction. Farm to school programs relate students to local food systems by purchasing local foods in the cafeterias, tours to the farm, visiting the farm, and incorporating local food and agriculture into school curriculums. These projects benefit the local economy, eliminate food miles, supply of fresh and nutritious foods and genuine learning on local and food heritage. Some of the problems encountered are the supply logistics, cost differentials and institutional procurement processes which need change of policy. Improved education on sustainable agriculture focuses on organic agriculture, agroecology, permaculture, regenerative agriculture, integrated pest management, soil health, water conservation, and climate-wise agriculture. The students get to know biological principles of production in order to be sustainable and get to know about the difficulties that the farmers may go through such as economic pressures, climate changes, and deficit of knowledge. The perception of agriculture as a compound socio-ecological system generates system thinking and defies the paradigm of industrial agriculture.

Food justice analysis looks into unfair food access, the power concentration of food systems, exploitation of farmworkers, displacement of indigenous and small scale farmers and cultural appropriation of indigenous foods [125-127]. Critical food literacy empowers students to be aware of how race, class, and geography define food experiences, as well as envision and agitate toward food systems that are fair to everyone, where all people have access to culturally suitable, nutritious food. Sustainability-based nutrition education includes health- and environment-oriented nutrition education, with a focus on plant-based diets, foods with minimal processing, local foods, and cultural culinary practices. With the help of educating students on how their dietary habits influence their health and the health of the planet, students can make knowledgeable decisions about food, based on the various values. Cooking education also creates both practical skills in preparation of healthy sustainable foods and the appreciation of food. Food waste mitigation deals with the immense environmental effects on wasted foods by reduction of sources, food rescue and re-distribution, compost, and system redesign. Students implement waste audits, waste reduction programs, use composting programs, and analyze waste minimizing obstacles such as aesthetic policies, confusion of date labels, and production incentives. Indigenous food sovereignty movements recover longstanding food, food production practices, and food governance upset by colonialism. Students are taught about how indigenous communities strive to reclaim food traditions, conservation of heritage seeds, the reclamation of landscape and reclaiming of rights to decide on food systems. The material deals with the historical injustices and examples of self determination and cultural sustainability. Food production possibilities in cities are exhibited by urban agriculture consisting of community gardens, rooftop farms, vertical farms, and edible landscaping. Students learn about the role of urban agriculture in solving food access, green spaces, community building, and transitioning empty lots and facing such obstacles as land access, soil pollution, access to water, and zoning regulations. Animal welfare and livestock issues are the environmental and ethical concerns regarding the use of animals in agriculture as well as the possibilities of plant proteins, and cell-based agriculture. The students explore a variety of the cultural approaches to animal-human relations and food habits and cultivate critical thinking regarding difficult tradeoffs among environmental sustainability, animal rights, cultural beliefs, and nutritious requirements.

### *3.12 Education Energy and Built Environment.*

Energy literacy is a collection of knowledge regarding energy sources, energy conversion processes, the principle of energy conservation, the environmental effects, the costs of energy, and energy system social aspects [6,18,128-130]. Students discuss physics of energy, discuss energy consumption at the individual and social level, discuss renewable and non-renewable energy, compute carbon footprints, and plan energy-conservation plans. All abstract concepts are explained with a hands-on activity, such as the construction of a solar oven, modeling of a wind turbine, and constructing an energy audit. Solar, wind, hydroelectric, geothermal, and biomass energy technologies are presented using renewable energy education which also examines the principles, location needs, technological aspects, cost-efficiency, and environmental aspects of tradeoff. Technical knowledge is built in the process of student projects that design renewable energy systems to serve school or community level showcasing that clean energy transitions are feasible. The focus on renewable energy facilities at the location does give contact with real-life situations. There are energy efficiency measures in the behavioral change arena, technological enhancement and system design. Students explore building insulation, efficient appliances and lighting, smart grid technologies, passive solar design and urban planning methods that use less transportation energy. Computing energy saving, payback time and lifecycle cost estimates builds up quantitative energy and shows economic worth of efficiency. Green building education presents the field of sustainable architecture with the principles such as passive design, natural ventilation and natural lighting, sustainable materials, water and energy saving, integration of renewable energy, as well as healthy indoor environment. Students examine green building rating systems, building assessments, developer sustainable buildings, and researches on built environments and their impacts on wellbeing of occupants, and environmental footprints.

Analysis of the transportation systems studies the modes of transport choices, transportation infrastructure in an urban set up and the freight systems in a sustainable manner [131,132]. The students explore environmental effects of the various forms of transportation, examine the planning in urban cities that promotes active transportation and convenient transit, examine the technologies of electric vehicles, and visualize the redesigned mobility systems. Learning is related to action through personal transportation audits and promoting infrastructure to support a safe and active lifestyle by walking and cycling. Sustainable materials education focuses on extractions, processing, use and disposal of materials with perspective on life cycle thinking, renewable materials, recycled materials, toxicity, durable and end-of-life options. Students study the flows and cycles of materials in consumer products, research on sustainability alternatives, study novelties of biomaterials and bio-based plastics, and reflect on how material decisions influence environmental and social sustainability. The concepts of zero waste are in opposition to the practice of waste as unavoidable of waste, and focus on waste prevention, designing waste to be durable and recyclable, comprehensive recycling and composting, and systemic methods that eradicate the notion of waste. Students auditing waste, initiating zero waste projects, researching on the policies of Extended Producer Responsibility, and discussing obstacles to zero waste such as product design, missed infrastructure, and economic incentives towards disposability. Water systems education analyses freshwater resources, water cycles, water treatment and water distribution infrastructure, water conservation and water pollution, as well as water justice. Isaacs researches the ecology of the watershed, examines water footprint, conducts water conservation, testing water quality, and studies such technologies as the rainwater harvesting, greywater systems. The concept of water as human right and finite natural resource builds the thinking of sustainability. Climate responsive design: It is the architecture and urban design designed to respond to the local climate needs and also foresee the effects of the climate change. Vernacular architecture, passive cooling and heating systems, landscaping that suits the climate, and infrastructure that will stand even in case of extreme weather are all explored by students. These principles are used in designing projects, where people develop space reasoning and problem-solving values that are creative.

### *3.13 Biodiversity and Ecology Studies*

Biodiversity education is formed to gain the knowledge about the species diversity, genetic diversity and ecosystem diversity; ecological functions of biodiversity; dangers to biodiversity and conservation measures [34,133-135]. Students researches into the local biodiversity by using field and sampling protocols and also by identification of the species and get to know the global pattern and hotspots of biodiversity. Association with local species and eco systems is also very vital in achieving individual interests in conservation. Ecosystem services models also allow students to realize the existence of such essential benefits of ecosystems as clean water and air, pollination, climate regulation, soil formation, nutrient cycling, and cultural values [136-138]. These services have been relied upon in an economic way which reflects the values of such kinds of services. Nonetheless, there are those critical attitudes that emphasize the negative aspect of devaluing nature to serve human interests, but insist on the significance of intrinsic value. Habitat restoration projects involve genuine experience of conservation activities in which the students are allowed to deliver specific conservation efforts to adverse ecosystems by removing invasive species, planting native plants, control erosion, recreating streams, or creating animal habitats. These undertakings cultivate environmental knowledge, effective land management skills and supreme contentment through observable enhancements of the environment. The patterns of ecological succession and restoration can be followed through the long-term monitoring. Conservation biology exposes students to the concepts of population ecology, extinction, and habitat fragmentation, invasive species, overexploitation, and conservation approaches as reserved lands, wildlife corridors, captive breeding, and ecosystem management. Both examples of successful conservation interventions as well as current losses give objective case studies that give a story on both sides. The concept of endangered species makes the abstract concepts very personal and has ethical concerns of triage and priorities. Urban ecology reveals assumptions of nature as a phenomenon confined to the wilderness and shows the presence of biodiversity in cities and the ecosystem in built environments. The students explore city wildlife, green infrastructures, ecological roles of urban parks and trees along the streets, and possibilities of improving urban ecosystem. The concept of cities as ecosystems creates an appreciation of nature in the daily set-ups and the impacts of urbanization on the ecology are realized.

The education of marine and freshwater ecology caters to the aquatic environments that are now being subjected to pollution, overfishing, invasive species and climate change that are making the aquatic environment even more threatened. Students learn about aquatic food webs, research into the quality of water, examine effects of human actions, and examine ocean and freshwater conservations. Taking of field trips is done on streams, pond or coastal environments to give students hands-on experience. The pollinator conservation is applied to the alarming loss of bees and butterflies, among other pollinators, that are crucial to the production of food and the workings of the ecosystem. Students develop pollinator habitat, research their effects, and ecology and behaviors, and can be part of citizen science monitoring programs. On-school pollinator gardens can offer visible attainable conservation activities. Soil ecology exposes the biodiversity which lies beneath our feet and the significant functions of soil in the food production, carbon sequestration, water filtration and in the nutrient cycle. Students probe into soil living organisms, examine soil health, and examine sustainable soil management, and learn links between soil degradation and climate change. Composting programs exhibit both biological decomposition as well as enhancing the quality of the soil. Forest ecology education focuses on forest ecology, structure and functions of forests, types of forests in the world and region, forest ecology service, threats to the forests such as forest degradation and deforestation, and sustainable forest management. Students explore forest succession and its policy and economics, take part in planting trees and in forest restoration exploration. Outdoor education in forested settings is an immersive type of outdoor learning (forest schools).

### *3.14 Waste Management and Circular Economy*

The waste management education converts the knowledge regarding waste as a disposal issue to the management of resource as the opportunity of being the part of the circular economy. Students explore waste-generating trends, researching on the flow of materials, the environmental and social costs of

existing disposal systems, and translating alternatives on waste generation focusing on prevention, re-use, repair, recycling, and recovery of materials. The source reduction strategies are based on avoiding the generation of waste, the prudent use of existing products, including choosing these products based on their durability and relative lack of packaging, as well as lifestyle changes that lead to resource minimization throughout. Learners engage in waste auditing of significant sources, products alternatives of research, and bring in waste minimization programs. Waste shift comprehending is directed towards preventive methods of waste rather than the disposal downstream methodology. Reuse and repair projects also oppose the culture of disposability by extending the life of products through repair, creative reuse as well as sharing. Upcycling to creatively reuse discarded materials Repair cafes where students are taught to cope with broken objects Swap meets where usable goods are exchanged Upcycling evidences alternatives to disposal. Such activities build up of practice and challenge institutional obsolescence and economic systems that demand constant consumption. Recycling education deals with collection mechanism, sorting, recovery of materials, and problems of contamination, recycled material markets and constraints of recycling as a solution. Students explore local recycling systems, examine recycling signs and labels, perform audit of contamination, and examine the impact of world commodity markets on the economics of recycling. Recycled knowledge on the limitation of recycling will encourage prevention and prioritise reuse. E-waste education deals with the most rapidly increasing waste that has valuable elements and toxic substances that need special attention. Students explore lifecycles of electronics, the pressures on planned obsolescence and upgrade, consider the options of repair and refurbishment, and examine the topic of responsible recycling that would guarantee the adequate recovery of the materials and prevent injuries to the workers. The matter of status symbols and continuous upgrades is also doubted through the critical analysis of the trends of electronics consumption.

The waste of textiles is also gaining momentum as a series of products of fast fashion produce huge amounts of waste. Students explore and research the effect of the environmental actions of the fashion industry, find alternatives such as natural fabrics and organic cotton, engage in a clothing swap and textile recycling and learn basic sewing to repair and modify clothes. Recycled materials have been used in fashion design which is a project that incorporates the concept of sustainability. Plastic education talks about the widespread plastic pollution of soil and water, wildlife, ecosystems, microplastic growth of plastic, and insufficiency of the existing plastic management systems. Educating students on policy interventions, banning single-use plastics, researching on bioplastics and alternatives to plastics are activities that are carried out through beach and stream cleanups where plastic pollution is documented and students research on the topic. The design of the intent to make sustainable products and the production methods of many items has been changed to put the costs and burdens of waste management on manufacturers instead of municipalities and consumers by the introduction of the Extended Producer Responsibility policies. Students evaluate the functionality of these policies, the implementation of these policies across jurisdictions, and discuss ways that producer responsibility can be broadened to cover more types of products. The knowledge of policy creates a civic literacy and engagement potential.

Fig. 4 visualization analyzes institutional performance across multiple sustainability dimensions including carbon emissions (tons CO<sub>2</sub>/year), renewable energy usage (%), waste diversion (%), water conservation (%), and green curriculum coverage (%). It also shows budget allocation across different green education initiatives, helping institutions benchmark and optimize their sustainability efforts.



Fig 4: Institutional Sustainability Metrics and Resource Allocation

### 3.15 Indigenous Knowledge and Decolonization

By incorporating Traditional Ecological Knowledge into the green education, the environmental knowledge is being enhanced and the indigenous intellectual property of the kind that is either suppressed or taken over by the mainstream institutions is being acknowledged. Land-based learning lays stress on the direct experience and connection to specific sites as the basis of environmental knowledge and accountability. This pedagogy falls within the indigenous educational traditions of experience centered learning, mentoring, narrative and relationship to the ancestral land. On-land learning is useful to every student, and it is specifically important to education of indigenous students who can reconnect with their ancestral land and compliance. To decolonize curriculum, attention should be paid to the presence of colonial power relations in the form of educational content, teaching approaches, and institutions and the ways it is reflected in them. Decolonization can be pushed to a higher plane in environmental education by acknowledging indigenous communities as knowledge bearers and custodians over the land and not as its passive subject; questioning the concepts of wilderness which do not recognize the role of indigenous land management; exploring how environmental conservation has historically displaced indigenous communities; and examining current environmental injustices targeted against indigenous communities. The pedagogies based on Indigenous approaches such as talking circles, storytelling, ceremony, observation, modeling, and collaborative learning are alternatives to the didactic Western teaching approach. These methods focus on comprehensive learning that involves the use of heart, mind, body and spirit; relational responsibility to society and place and the respect of different styles in learning. Considerate incorporation of indigenous pedagogies is not only good to all learners but also helps to establish more accommodating

environments to indigenous learners. The sovereignty and self-determination concepts acknowledge the rights of the indigenous people to manage their own learning, knowledge, settlement and destiny. Green education with a respect to sovereignty promotes education directed by indigenous people, requests authorization and due acknowledgement to native knowledge disseminated, and promotes native rights in the setting of environmental choices. Non indigenous educators do not use this indigenous knowledge in an appropriating way, but use it in a humbled and respected way. Two-eyed seeing styles combine indigenous and Western systems of knowledge and appreciate the advantages of both but perceive destructions of a different epistemology. This framework is interested in the fact that neither system is sufficient in itself and does not seek to subordinate it to the other. The students are taught to value various systems of knowledge and be able to move after one another.

Table 2: Emerging Technologies, Applications, and Future Directions in Green Education

Sr. No.	Technology/Innovation	Application Areas	Benefits	Implementation Challenges	Current Limitations	Future Directions
1	Artificial Intelligence	Personalized learning pathways, intelligent tutoring, data analysis, pattern recognition	Individualization, scalability, sophisticated data interpretation	High costs, technical expertise requirements, algorithm bias concerns	Limited emotional intelligence, dependence on quality training data, equity issues	Advanced personalization, emotional AI tutors, predictive interventions, bias mitigation
2	Virtual Reality	Ecosystem immersion, climate future visualization, inaccessible location exploration	Geographic barriers removed, safe experiential learning, empathy development	Equipment costs, motion sickness, technology maintenance	Limited tactile experience, isolation from actual environment, hardware requirements	Haptic integration, multiplayer environments, lower costs, educational content expansion
3	Augmented Reality	Real-time information overlay, field guide enhancement, spatial visualization	Enhances rather than replaces real environments, contextual information, engagement	Device requirements, distraction potential, development complexity	Battery life, limited field of view, content development needs	Lightweight wearables, AI integration, crowdsourced content, seamless integration
4	Gamification Platforms	Engagement enhancement, sustainability challenges, simulation learning, behavior change	Motivation increase, safe experimentation, immediate feedback	Superficial engagement risk, development costs, game design expertise	Individual focus over collective action, competition stress, limited depth	Collaborative designs, sophisticated narratives, real-world integration, adaptive difficulty
5	Blockchain Technology	Sustainability credential verification, carbon credit tracking, supply chain transparency	Transparency, tamper-proof records, decentralized verification	Technical complexity, energy consumption, scalability concerns	Limited adoption, user interface complexity, environmental footprint	Energy-efficient protocols, user-friendly interfaces, wider adoption, educational applications
6	Citizen Science Apps	Data collection, species identification, environmental monitoring, research participation	Authentic science contribution, large-scale data gathering, student motivation	Data quality concerns, sustained participation challenges, technical barriers	Requires smartphone access, potential data privacy issues, participation inequality	AI-assisted identification, gamification integration, federated learning, privacy protection
7	Learning Management Systems	Content delivery, progress tracking, collaboration facilitation, assessment management	Organization, accessibility, personalization, data collection	Platform learning curve, student screen fatigue, technical problems	Generic rather than sustainability-specific, limited offline access, data privacy	Sustainability-focused LMS, offline capabilities, adaptive learning, better privacy
8	Internet of Things Sensors	Real-time environmental monitoring,	Hands-on data work, immediate feedback,	Cost, maintenance, technical	Limited sensor lifespan, calibration needs,	Lower costs, improved reliability, AI

		building systems control, data collection	authentic applications	expertise, connectivity requirements	data interpretation challenges	interpretation, broader deployment
9	Drones and Remote Sensing	Aerial photography, land mapping, wildlife monitoring, inaccessible area access	Spatial perspective, efficiency, safety for hazardous sites	Regulations, costs, piloting skills, weather dependency	Battery limitations, regulatory restrictions, privacy concerns	Longer flight times, AI autonomous operation, miniaturization, regulation harmonization
10	Geographic Information Systems	Spatial data analysis, mapping, land use planning, environmental change tracking	Visual communication, spatial thinking development, real-world applications	Software complexity, data acquisition, learning curve	Technical barriers for beginners, data costs, interpretation expertise needed	User-friendly interfaces, open data expansion, cloud-based platforms, educational modules
11	Climate Modeling Software	System dynamics exploration, scenario testing, policy impact simulation	Complex system understanding, future exploration, decision support	Technical complexity, computational requirements, validation challenges	Simplified models may miss nuances, requires background knowledge, output interpretation	Accessible interfaces, enhanced visualization, model linking, uncertainty communication
12	Social Media Platforms	Campaign organization, knowledge sharing, community building, advocacy	Wide reach, peer influence, rapid information spread, networking	Misinformation spread, privacy concerns, platform algorithm control	Echo chambers, short attention spans, corporate control, distraction potential	Educational networks, verified information systems, reduced manipulation, attention management
13	Digital Storytelling Tools	Multimedia narrative creation, student voice amplification, documentation	Creative expression, authentic audiences, technology integration	Time intensive, equipment needs, technical skill requirements	Quality variation, evaluation challenges, equity in access	AI editing assistance, template libraries, easier interfaces, broader platform integration
14	Video Conferencing	Global collaboration, expert connection, virtual field trips, distance learning	Geographic barriers eliminated, cost reduction, diverse perspectives	Technology barriers, fatigue, time zones, internet requirements	Limited physical interaction, screen fatigue, technical difficulties	Improved interfaces, virtual collaboration tools, hybrid models, better bandwidth
15	Mobile Applications	On-demand learning, field guides, data collection, behavior tracking, challenge participation	Accessibility, convenience, ubiquity, real-time information	Device requirements, digital divide, distraction concerns	Screen size limitations, app overload, battery drain, privacy issues	Offline functionality, better integration, AI personalization, reduced battery use
16	3D Printing	Prototyping sustainable designs, replacement part creation, sustainable material exploration	Tangible creation, rapid iteration, reduced material waste in prototyping	Equipment and material costs, time requirements, environmental concerns of some materials	Material limitations, print time, technical expertise, energy consumption	Sustainable material development, faster printing, lower costs, user-friendly operation
17	Renewable Energy Kits	Solar panels, wind turbines, experimentation, system design learning	Hands-on learning, technology demystification, practical skills	Costs, maintenance, storage, curriculum integration needs	Kit limitations versus real systems, weather dependency, component failure	Better durability, lower costs, IoT integration, expanded capabilities
18	Environmental Simulation Games	Climate negotiation, ecosystem management, policy testing,	Safe complex decision practice, perspective diversity, engagement	Simplification necessary, time demands, transfer to reality questions	Fidelity limitations, gameplay over learning potential, accessibility	Improved realism, collaborative multiplayer, AI NPCs, learning

		stakeholder perspective-taking				analytics integration
19	Biodiversity Databases	Species information access, research support, identification tools, distribution mapping	Comprehensive information, visual learning, authentic data	Overwhelming information, curation quality variation, internet requirements	Gaps in coverage, expertise needed to interpret, taxonomy changes	AI curation, better visual interfaces, offline access, citizen contributions integrated
20	Carbon Footprint Calculators	Personal impact quantification, lifestyle comparison, reduction strategy testing	Behavior awareness, goal setting, impact visualization	Accuracy limitations, data demands, overwhelming results potential	Estimation rather than precision, boundary challenges, comparative difficulties	Improved accuracy, automated data collection, social comparison features, actionable recommendations
21	Smart Building Systems	Energy optimization, occupancy management, environmental condition monitoring	Efficiency improvements, data generation for learning, comfort	High costs, complexity, privacy concerns, maintenance	Technical failures, user interface challenges, data interpretation needs	AI optimization, predictive maintenance, better interfaces, cost reduction
22	Agricultural Technology Tools	Precision agriculture, soil testing, crop monitoring, weather prediction	Efficiency, reduced input waste, data-driven decisions	Costs, technical complexity, small-scale farm suitability questions	Technology access inequity, data privacy, corporate control concerns	Smallholder-appropriate tech, open-source platforms, reduced costs, farmer sovereignty
23	Water Quality Testing Kits	Chemical and biological testing, monitoring over time, citizen science contribution	Hands-on science, authentic data, local relevance	Calibration needs, consumable costs, result interpretation	Test limitations, laboratory confirmation needs for some parameters, costs	Lower costs, broader parameter testing, smartphone integration, easier interpretation
24	Wearable Environmental Sensors	Personal exposure monitoring, health connection demonstration, data collection	Personal relevance, health connections, mobility	Privacy concerns, costs, discomfort, data management	Limited parameters, accuracy questions, battery life	Miniaturization, expanded sensing, better accuracy, privacy protection
25	Open Educational Resources	Free curriculum access, adaptation possibilities, global knowledge sharing	Cost elimination, customization, broad access	Quality variation, findability challenges, sustainability of creation	Curation needs, lack of local contextualization, technical barriers	Better curation, AI customization, quality assurance, contextual adaptation support
26	Artificial Intelligence Content Generation	Curriculum development support, personalized materials, assessment creation, translation	Efficiency, personalization, accessibility, translation	Accuracy concerns, bias, over-reliance, creativity limitations	Hallucinations, cultural insensitivity, homogenization, displacement of human expertise	Improved accuracy, bias reduction, teacher augmentation rather than replacement, verification tools
27	Biometric Feedback Systems	Stress monitoring, engagement measurement, nature connection assessment	Objective engagement data, wellbeing monitoring, research insights	Privacy invasion, interpretation challenges, equipment costs	Limited understanding of causation, individual variation, ethical concerns	Non-invasive monitoring, AI interpretation, privacy protection, ethical frameworks
28	Virtual Labs	Experimental simulation, hazardous procedure practice,	Safety, accessibility, repeatability, cost reduction	Limited tactile learning, authenticity questions,	Cannot fully replace hands-on lab work, simulation fidelity	Improved realism, haptic feedback, hybrid approaches,

29	Blockchain for Education Credentials	equipment access democratization Skill verification, micro-credentialing, portable transcripts, fraud prevention	Verification ease, student ownership, fraud reduction	technology requirements Technical complexity, limited adoption, energy concerns	limits, technology barriers Ecosystem fragmentation, privacy questions, environmental footprint	adaptive scaffolding Green blockchain protocols, wider adoption, user-friendly interfaces, interoperability
30	Predictive Analytics	At-risk student identification, intervention targeting, resource optimization, outcome prediction	Early intervention, resource efficiency, personalization	Privacy concerns, bias perpetuation, self-fulfilling prophecy risks	Accuracy limitations, ethical concerns, reduces students to data points	Bias mitigation, transparency, human oversight, ethical frameworks, student agency preservation

In environmental education Language revitalization relates environmental education to indigenous language revitalization, as ecological knowledge and cultural relations with the environment are coded in language. The indigenous languages have conceptual frameworks that can be shown by the use of environmental vocabulary that show differences with those of dominant languages. The healing of the language and land takes place concurrently where the indigenous young people are taught the ancient language as they reconnect with the ancestral lands and emotions. The atmosphere of traditional food systems such as hunting, fishing, gathering, agriculture is the sustainability that was established through generations. Traditional food learners gain skills, cultural understanding, and connections to the source of food as they learn practical studies that help them learn how to harvest food and how to prepare it, as well as to form connections and relations to food sovereignty movements that seek to reclaim disrupted food systems through colonization. Climate change as viewed by the indigenous people understood that indigenous people are being disproportionately affected by climate change despite being the least contributors to greenhouse gases. Through indigenous climate knowledge of traditional knowledge, observations help in complementing scientific observations and indigenous adaptation strategies can teach the wider society. The indigenous climate justice movements are calling on the fact that climate policy should be informed by indigenous rights and knowledge.

### 3.16 Health and Wellbeing Connections

Planetary health views environmental health as essential in human health and these effects form linkages between environmental degradation and human disease burden taking the form of air and water pollution, climate change effects, biodiversity decline in disease control, and food systems perturbation. Students research certain health environment interactions such as air pollution-induced asthma, waterborne diseases, proliferation of vectors with surge in temperature, and the psychological effect of environmental deterioration. The results obtained through nature connection and wellbeing studies prove that time in nature will have psychological and physiological positive effects such as the reduction of stress, restoration of attention, mood lift and promotion of physical activity. These benefits are seen in outdoor learning, forest bathing, wilderness programs, and the incorporation of the elements of nature in the schools. Knowledge of the healthy side of nature gives an individual incentive towards environmental responsibility and puts barriers to the inactive lives of screens. Environmental justice Environmental justice studies the inequitous distribution of the pollution burden, climatic vulnerability, and environmental amenities based on race and economic status. Students explore and research on environmental health inequities in their local environments, interpret historical policy formation of the patterns, and also campaign on equal environmental health guarantees. This content builds critical awareness of health inequality coupled with personal health issues that relate to the issue of systemic injustice. Sustainable nutrition brings health and environmental concerns in nutrition guidelines. Students evaluate the positive effects of plant-based diets and global health, explore the concept of sustainable protein, learn the topic of relationships between soil health and nutritional density, and consider the topic of how the sustainability of food systems influences food security and nutrition well-being. Such combined strategy does not isolate the information about health and environment. Active

means of transportation such as walking and cycling are encouraged in regard to environmental advantage as well as health advantage. Learners explore barriers and facilitators to active transport, examine urban design features that assure active mobility, as well as promote safe infrastructures, walk-to-school and bike-to-school programs. The expression of transportation decisions relating daily physical exercise to a decreased amount of emissions shows the personal applicability of sustainability. Also covered by the toxic chemicals education is the environmental health danger posed by pesticides, plastics, and air pollutants, along with other chemicals that surround contemporary lives. Students study chemical exposures, study the effects of health, examine the methods of the precautionary principle, and practice harm reducing methods. Chemical health risk awareness can drive sustainable consumption where through science literacy and skeptical thinking of product claims and evaluations are developed. Mental health and climate anxiety get separate consideration since great quantities of youths tend to experience anxieties, grief, and unhappiness over reduced climate change and environmental decay. It is critical to supply accommodative grounds to work through these feelings, find people that care about the same problem, and use suffering to produce productive action. Schools come up with guidelines of helping the students with emotional wellbeing in matters touching on the environment. Nature-based interventions and ecotherapy involve the social environment of mental health promotion and treatment. Students get to know about the horticultural therapy, the wilderness therapy, the animal-assisted interventions and nature mindfulness. These interventions are implemented in school gardens, green schoolyards and outdoor classrooms where it is shown that institutions are concerned about the wellbeing of students through environmental quality.

In the environmental industries, occupational health deals with the safety of workers in the agricultural industry, during waste management, the rehabilitation of the environment, and in other matters that relate to the green industry. Students explore the nature of occupational hazards, ways sustainable practices can enhance the safety of workers as well as labor rights and worker organizing in the environmental sectors. This writing does not allow romanticizing environmental work and forges awareness of labor aspects of just transition. Investigations of arts, humanities and environmental imagination usually encompass environmental studies and rhetoric, along with criticism of arts and the environment and its histories. Arts, Humanities and Environmental Imagination Investigations in the arts, humanities and environmental imagination typically include environmental studies and rhetoric, and also criticism of arts and the environment and its histories. Environmental humanities incorporate environmental topics, the study of the environment with literary studies, philosophy, history, religious studies, and cultural studies to understand how human meaning-making, values, stories and imagination influence environmental relationships and possibilities. It is in this interdisciplinary area that it is acknowledged that environmental issues can be solved not only by technical means but also by restructured consciousness, values and narratives of human place in more-than-human world. Eco-literature, nature writing gives the students an introduction to authors discussing the human-nature connectivity, environmental ethics, and the ecological awareness in a wide range of literary genres. Environmental themes in literature Analysis builds a critical reading and exposes the knowledge of the environment as being created by language and narrative. Writing activities that are creative allow the learner to express his own environmental experiences and vision in the form of poetry, essay, and fiction. The philosophy of environment deals with some fundamental questions concerning the intrinsic value of nature, moral consideration of non-human beings, ethics between generations, environmental justice and responsible human relationships with the nature. The various philosophical traditions that students are exposed to are deep ecology, ecofeminism, social ecology, indigenous philosophies, as well as, environmental pragmatism. Philosophy formulates argumentative stands of intricate questions of the environment that accommodate a number of plausible standpoints.

Environmental history studies the interaction of the past societies with the environment, which has produced both warning stories of environmental destruction and instances of sustainability. The historical approach deals with the question of how the economic systems, technologies, the cultural values, and the relations of power were derived to make the changes in the environment and also how the environment was affected by the changes in social. The skills of definition of the historical contingency refute the concept of environmental determinism and show other avenues. Environmental justice art exposes environmental injustices, honors environmental death, envisions sustainable social

realities, and organizes surrounding action to protect the environment. Students discern the manner in which artists tackle environmental themes, develop their own eco-art environments and consider in what ways art holds a complementary relationship to scientific and policy responses to environmental concerns. Environmental messages of students are magnified outside school communities because of public art projects. The use of film and media literacy on environmental content can be used to critically analyze environmental discourse and other environmentally-related information in documentaries, news, entertainment, advertising, and in social media. The students explore the way the media reflect environmental issues, the viewpoints that prevail, the information to be brought to the fore or lose its place and how emotional appeal is used. The media production projects help students to make interesting environmental stories. Music and sound ecology investigate the connection between sound, environment and human experience. Learners explore phenomena of acoustic ecology, develop soundscape compositions, and examine environmental topic in music, as well as examine issues of noise pollution on human and wildlife wellbeing. Sound walks and recording projects enable the development of listening to the sound of the environment that is often ignored.

Theater and performance has been dealing with environmental issues in different types of dramas such as realistic drama, physical theater, and puppetry, and interactive performances. Students practice the already existing environmental plays, invent their own work which will contribute to the local environmental problems and will investigate the methods to develop the environmental empathy and collective imagination of working in the theatrical techniques such as embodiment and ensemble. Design thinking in environmental problems incorporates innovative thinking, compassion, systems thinking and prototyping. The students define environmental issues, investigate stakeholder views, brainstorm, develop prototypes, experiment with users, and maintain the designs. In this approach, innovation capacity is built, and apparent artifacts to deal with practical environmental requirements are generated. Science fiction and speculative fiction exploring the future of climate futures and ecological change and sustainable cultures can explore the possibilities beyond the present limitations. Climate fiction are read and students are asked to construct fictional situations and evaluate how future imaginaries define the present action. When looked at with an atrocious understanding, both dystopia and utopia play a role in encouragement of environmental knowledge.

#### **4. Conclusions**

This is in the sense that this extensive literature review has found that green education has been able to transform the limited-based environmental awareness campaigns as comprehensive, multi-dimensional pedagogical frameworks of environmental stewardship, social justice and economic viability. The fact that 147 recent scholarly outputs are synthesized shows that effective green education needs to be holistic and transcendental across different boundaries and include various stakeholders, respect diverse knowledge systems, and promote transformative learning that questions deep-rooted assumptions on human nature relationship and sustainable futures. The discussion is able to determine some of the key success factors of effective green education. Initially, the curriculum crosscutting is more effective than separate courses in the environment, and the principles of sustainability have effective penetration into mathematics, language arts, social studies, sciences, arts, and all spheres of education. Second, embodied knowledge generated through field studies, community projects, place-based investigations, and gardens and environmental studies cannot be accomplished through abstract instruction. Third, authentic action opportunities allow students to have meaning in the use of knowledge, develop efficacy and long-term commitment, which are only achieved through active learning. Fourth, development of systems thinking prepares the learner to work in a complex world, admit interconnections, and envision unintended consequences necessary to solve wicked sustainability issues. Fifth, there are the dimensions of equity and justice that have to be explicitly looked at, discussing the ways in which environmental burdens and benefits allocate and inequitably as well as ways in which education can preserve or question these trends.

The emergence of new technological innovations increases the possibilities of green education but poses valuable equity and pedagogical challenges. The technologies of artificial intelligence, virtual reality, gamification, citizen science websites, and sensors in the Internet of Things can be useful instruments

to promote individualized learning, immersion, engagement, real research, and real-time environmental surveillance. Nevertheless technologies must be thoughtfully put into use that would make them accessible and not replace face-to-face nature and embodied learning without losing critical views of technological solutions, and challenging digital barriers, which would only intensify educational disparities. Theoretical terrain Theoretical frameworks involved transformative learning, experiential learning, critical pedagogy, indigenous knowledge systems, systems thinking, and action competence frameworks. Efficient practice is based on various and theoretical resources instead of dogmatic rules and principles of the single approaches and cultural responsiveness and local relevance of the practice depend on the contextual adaptation. Green education specifically incorporating indigenous knowledge is beneficial and presents alternative epistemologies with a focus on reciprocity, interrelatedness, and long-term orientation as well as dealing with the attempts at marginalization of indigenous voices in historical education and modern land and knowledge sovereignty movements. The issue of assessment innovation arises and the conventional knowledge assessments are not enough to measure the complex sustainability competencies such as values, dispositions, skills and behavioral intentions. Long-term follow-up tracking, sustained impacts are done through comprehensive assessment which uses a variety of tools such as performance tasks, portfolios, self and peer assessment, behavioral observation, systems thinking evaluation, and long-term follow-up. Creating a balance between the demands of accountability and formative assessment in the support of the learning process, the recognition of the diversity of knowledge and its manifestations, and the avoidance of decreasing sustainability into easily measurable parameters cannot be performed in one activity. Teacher preparation and professional development becomes fundamental but inadequate in most of the cases. Pre-service and in-service education should cultivate the sustainability literacy of teachers, their pedagogical content knowledge, facilitation skills, and individual commitment as well as have a psychological focus on anxiety and a sense of hope despite overwhelming impediments. On-going teacher mentorship and participation in action research as well as leadership development promote continuous teacher development. Nevertheless, structural assistance such as curriculum materials, administrative resources, community associations, and policy areas that allow individual teacher potential to be converted into organizational change have become indispensable to individual teacher capacity.

Green education has become a part of policy and governance frameworks, and locally sustainability education is becoming compulsory or even promoted by curriculum requirements, teacher licensing, school accreditation and specifically funded in more and more jurisdictions. The international structures assist in offering direction on the same with national and local policies defining the details to be exercised. Coherent sustainability learning environments are developed when whole-institution strategies in harmonizing curriculum, campus activities, governance and community relations are in place. Youth voice is substantive in the process of student engagement in environmental governance, and these competencies are the civic ones. The climate change education has become especially acute, there is need to balance the scientific knowledge, emotional condition processing of anxiety and grief, critical examination of the political aspects, and finding the power of the agency-based action. Climate education should not be catastrophic along with false optimism that undermines real threats or hopelessness along with despair but develop realistic hope based on the knowledge that radical change is still feasible with enough of a collective mind and effort toward it. Climate change has predetermined specific pedagogical issues and prospects of inter-generational character, and youth are fully entitled to worry about futures in which they will be living, yet they did not shape up. Specific array of sustainability domains such as food systems, energy, built environment, biodiversity, waste management, and additional aspects may concur on the key content, and should exhibit the relationship between environmental, social, and economic aspects. Combined/Integrated strategies assist learners in understanding our ability to see how the collective/system level influences cause changes in other areas and how one arena of intervention can have side effects on another. Local inquiries of sustainability problems do make a relevance and actability whereas global inquiries do ward off parochialism and establish the unity on cross-contextual grounds. Service learning, partnerships, intergenerational exchange, participatory action research, and environmental volunteering post-institutional and institutional learning to families, neighborhoods and civic spaces by engaging in community engagement. These relationships ensure a personal relevance of sustainability in both personal and professional aspects of life, authentic action opportunity and social capital as well as community

benefits and student learning. Yet, to guarantee reciprocity and prevent situations when the communities should become the oasis of extracting student learning, careful do not miss the opportunity of developing partnerships.

The green education expansion and deepening is limited by a number of persistent challenges. Educators are bound by the limitations of resources such as funds, time, materials, and availability of expertise to do what they may have been committed and creative to do. Unfavorable institutional inertia, competing priorities, high-stakes testing pressures and political resistance are some of the factors that make transformative change a challenge. There is a tendency to have insufficient preparation of teachers so that they feel unprepared to the complexity of sustainability education. Hurdles in assessment of non-measurable or long-term transformations or holistic outcomes of evaluation pose a challenge to accountability systems that were created with the goal of easily measurable knowledge acquisition. Disparities in the access to green education and other environmental facilities are issues that need to be addressed explicitly so that the concept of sustainability is not enforced on the privileged communities. Balancing optimism and integrity in regard to the issue of sustainability puts the learning frontiers of educators to task concerning how to be able to address unpleasant realities without creating paralysis. Some opportunities that can be explored to encourage the progress involve thinking strategically about technological innovation, enhancing community relationships, integrating indigenous knowledge systems, joining social movements on climate justice and environmental equity, establishing international collaboration and knowledge exchange, proving sustainability as basis of flexible post-pandemic education systems instead of supplement to business as usual.

The future research directions that can arise due to this review can be considered as longitudinal studies with the problem of determining the effects of green education in the long-term perspectives such as career pathways, civic engagement, lifestyle changes, and continuous learning several years after the formal interventions. International comparative studies of the way different cultural, political, and economical contexts influence the effectiveness of green education may bring transparency to identify issues of transferability and adaptation needs. Research that is equity-based looking into the impact of green education on marginalized individuals and the opportunity to interfere with the outcomes of interventions or to alleviate or worsen educational imbalances should be given priorities. The integration research on technology should be in step with the high-speed innovation, analyzing the effectiveness, equity and the best implementation. Theoretical perspectives and applications Theoretical work and practice Theoretical interests and applications Multidisciplinary and transdisciplinary scholarship with green education and areas such as public health, urban planning, social innovation, and democratic theory have potential. Evidence-based practices that require effective implementation on pilot projects but not large-scale implementation would be studied through the application of implementation science to facilitate system-level change. Research on integration of indigenous knowledge that is led by indigenous scholars would help in proper and respectful integration of traditional knowledge systems. Creation of assessment innovation research based on the creation of valid, reliable, and feasible processes of measurement of complex sustainability competencies is still essential. There are a number of strategic measures that can be implemented by the practitioners to progress green education. Begin where you can in present circumstances not waiting until the right time comes but understand that small steps will work towards transformation. Work together with interdisciplinary teams, silo busting, and developing shared capacity. Involve the students as participants in the sustainability efforts, respect their opinions, and empowerment. Community partnerships through which they offer genuine learning environments and win-win situations. Champion institutional and policy modifications to allow a more profound incorporation of principle of sustainability. Continue to learn by engaging in professional development, peer exchange and reflection. Inventions and innovations should be shared and documented to create common knowledge. Be hopeful and strong with the help of the community and self-care practices. Lead by example and set sustainable activities at personal and work life recognising the existence of flaws but showing a good example. Embrace sustainability education as practice not as subject matter to be learned but as radical practice involving pathways of the heart, mind, and hands of all participants in the process of shared travel towards viable, equitable, fulfilling futures on finite planet.

## Author Contributions

AP: Conceptualization, visualization, writing original draft, writing review and editing, and supervision.  
JR: Data collection, methodology, resources, visualization, writing original draft, writing review and editing, and supervision.

## Conflict of interest

The authors declare no conflicts of interest.

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