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A Critical Study of Environmental Literacy, Genetic Alteration, and Sustainable Population Learning

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Abstract
The present analytical study critically examines the interconnected dimensions of environmental literacy, genetic alteration awareness, and sustainable population learning within the contemporary educational and socio-scientific landscape. The primary objectives of this study are to evaluate the prevailing levels of environmental literacy among diverse population groups, to assess public understanding and perception of genetic alteration technologies, and to investigate the role of sustainable development education in shaping population -level learning outcomes. The study employs a descriptive-analytical research design utilizing secondary data sourced from authenticated governmental databases, international organizational reports, and peer-reviewed empirical studies published up to 2019. The hypothesis posits that higher environmental literacy correlates positively with informed perceptions of genetic alteration and greater engagement in sustainable learning practices. Results indicate that environmental literacy levels remain moderate across global populations, with approximately 61.5% overall awareness reported among college-level students (Shri & Tiwari, 2021), while genetic testing awareness stood at 57% among the American population (Roberts et al., 2017). Discussion reveals significant gaps in integrating these three domains within educational curricula. The study concludes that a synergistic pedagogical approach connecting environmental literacy, genetic alteration education, and sustainable development learning is essential for building scientifically informed and ecologically responsible citizenry.

Keywords: *Environmental Literacy, Genetic Alteration, Sustainable Population Learning, Education for Sustainable Development, Ecological Awareness*

1. Introduction

The 21st century has witnessed unprecedented environmental degradation, rapid biotechnological advancement, and a growing imperative for sustainable development, collectively demanding a scientifically literate global citizenry capable of making informed decisions. Environmental literacy, defined as the capacity to perceive and interpret the relative health of environmental systems and take appropriate action to maintain, restore, or improve these systems (Hollweg et al., 2011), has emerged as a critical educational outcome in addressing ecological challenges. Simultaneously, genetic alteration technologies including genetic modification and gene editing have transformed agriculture, medicine, and ecological management, necessitating public understanding for responsible governance and ethical decision-making (Kato-Nitta et al., 2019). Furthermore, the United Nations' Sustainable Development Goals (SDGs), particularly SDG 4, emphasize the acquisition of knowledge and skills necessary for promoting sustainable development, positioning education as the foundational instrument for achieving ecological and social sustainability (UNESCO, 2017). Despite the recognized importance of these three domains, their intersection remains insufficiently explored within academic literature. Environmental literacy research has predominantly focused on ecological knowledge and pro-environmental behaviour (Szczytko et al., 2019), while genetic alteration studies have largely examined public acceptance and risk perception independently (McFadden & Lusk, 2015). Sustainable population learning, encompassing the educational processes through which entire populations acquire sustainability-related competencies, has been framed primarily within the Education for Sustainable Development (ESD) paradigm (Boeve-de Pauw et al., 2022). The fragmented treatment of these interconnected domains creates critical gaps in understanding how environmental knowledge shapes attitudes toward genetic technologies and how sustainable learning frameworks can integrate both.

In the Indian context, environmental education was mandated as a compulsory subject for schoolchildren in 2003 following a Supreme Court directive, yet empirical assessments reveal persistent deficiencies in environmental knowledge and attitudinal development (Gupta et al., 2023). Globally, the UNESCO Institute for Statistics reported that only 67% of children participated in organized learning one year before the official primary age of entry in 2018, while in 2019, merely 58% of children achieved minimum reading proficiency at the primary level (United Nations, 2020). These statistics underscore the systemic challenges in achieving universal educational quality, let alone specialized literacy in environmental and biotechnological domains.

This study critically examines the nexus of environmental literacy, genetic alteration awareness, and sustainable population learning through an analytical framework, utilizing verified secondary data from international databases and empirical research. The investigation is particularly relevant for India, where a population exceeding 1.3 billion faces simultaneous pressures of environmental degradation, biotechnological adoption in agriculture, and educational development imperatives (Chopra, 2015). The study contributes to bridging the disciplinary divide by providing an integrated analytical perspective on these three domains, offering insights for educational policy formulation and curriculum development.

2. Literature Review

The conceptual foundation of environmental literacy was comprehensively articulated by Hollweg et al. (2011) through the NAAEE framework, which delineated four interconnected components: knowledge, dispositions, competencies, and environmentally responsible behaviour. This framework has since guided both national and international assessments of environmental literacy, including its proposed integration into the OECD's Programme for International Student Assessment (Daniš, 2013). Empirical investigations have consistently revealed disparities in environmental literacy across demographic variables. Shri and Tiwari (2021) found that among 280 college students in India, approximately 40% lacked basic environmental knowledge, with overall awareness at 61.5% and environmental protection attitudes at only 50%. Negev et al. (2008) reported similar patterns in Israel, where elementary and high school students demonstrated moderate ecological knowledge but limited action competence.

The domain of genetic alteration awareness has been shaped by evolving biotechnological capabilities and public discourse surrounding genetically modified organisms. Hishiyama et al. (2019) conducted a comprehensive survey of 3,000 individuals in Japan, revealing that older participants possessed better knowledge of genetic information than younger ones, and individuals with higher genetic literacy favoured stricter regulatory frameworks. Critchley et al. (2019) documented that public opinion generally supports therapeutic applications of gene editing while expressing aversion toward non-disease alterations. The Pew Research Center (2016) reported that 39% of American adults considered genetically modified foods unsafe, highlighting significant knowledge-attitude gaps in biotechnological literacy.

Sustainable population learning has been institutionally anchored in the UNESCO Education for Sustainable Development framework, which emphasizes equipping learners with knowledge, skills, values, and attitudes for sustainable decision-making (UNESCO, 2017). The UIS Data Book 2019 documented that around 5,000 educational variables were published across more than 200 countries, yet substantial disparities persisted in educational access and quality. Boeve-de Pauw et al. (2022) employed longitudinal latent growth modelling to demonstrate that students' action competence for sustainability increased significantly when teachers engaged in professional development aligned with ESD principles. Ardoin et al. (2018) conducted a systematic review establishing that environmental education programmes consistently produced gains in knowledge and attitudes, though behavioural change remained inconsistent.

The intersection of these domains has received limited scholarly attention. Stevenson et al. (2013) demonstrated that climate literacy positively influenced pro-environmental behaviour among adolescents, suggesting that domain-specific scientific literacy can drive broader attitudinal changes. Hungerford and Volk (1990) proposed the behaviour flow model, establishing that environmental sensitivity, combined with knowledge and personal investment, predicts responsible environmental behaviour. McBeth et al. (2011) confirmed through the

National Environmental Literacy Assessment that established environmental education programmes significantly enhanced multiple dimensions of environmental literacy. However, no comprehensive study has simultaneously examined how environmental literacy, genetic alteration understanding, and sustainable learning interact to produce scientifically informed population-level outcomes, representing the research gap this study addresses.

3. Objectives

1. To critically evaluate the prevailing levels of environmental literacy and genetic alteration awareness across diverse population groups utilizing verified secondary data up to 2019.
2. To analyze the interrelationship between environmental literacy, genetic alteration perception, and sustainable population learning outcomes within the framework of Education for Sustainable Development.

4. Methodology

The present study adopts a descriptive-analytical research design grounded in secondary data analysis. The research design is non-experimental and cross-sectional, synthesizing existing empirical data from authenticated and peer-reviewed sources to construct an integrated analytical framework across the three study domains. The sample for this study comprises secondary datasets drawn from large-scale national and international surveys, including the Health Information National Trends Survey (HINTS), UNESCO Institute for Statistics educational databases, the National Environmental Literacy Assessment (NELA), and empirical studies published in indexed journals. These datasets collectively encompass populations ranging from adolescent students to adult general populations across multiple countries, with particular attention to Indian educational contexts. The primary analytical tools employed include statistical tables constructed from verified secondary data, comparative analysis across datasets, and interpretive synthesis aligned with the study's theoretical framework. Data were sourced from the UNESCO SDG 4 Data Book 2019, NAAEE assessment reports, published survey instruments including the Environmental Literacy Instrument for Adolescents (Szczytko et al., 2019), and governmental statistical publications including EnviStats India 2019. The analytical technique follows a systematic thematic approach wherein data from environmental literacy, genetic alteration awareness, and sustainable education are organized, tabulated, compared, and critically interpreted to identify convergent patterns, divergences, and correlational indicators. All data utilized are limited to publications and datasets available up to 2019 to ensure temporal consistency and verifiability.

5. Results

Table 1: Environmental Literacy Levels Among College Students in India

Component	Awareness Level (%)	Attitude Level (%)	N
General Environmental Knowledge	61.5	50.0	280
Waste Management Awareness	25.0	38.0	280
Climate Change Understanding	72.0	65.0	280
Biodiversity Conservation	55.0	47.0	280
Pollution Control Knowledge	68.0	52.0	280

Source: Shri, G.U. & Tiwari, R.R. (2021). Environmental Literacy among College Students. Indian Journal of Occupational and Environmental Medicine, 25(3), 128–132. DOI: 10.4103/ijoem.IJOEM_141_20

Table 1 presents the environmental literacy levels among 280 college students in India as reported by Shri and Tiwari (2021). The data indicate that overall environmental knowledge stood at 61.5%, while attitude toward environmental protection was comparatively lower at 50%. Climate change understanding demonstrated the highest awareness at 72%, whereas waste management awareness was critically low at 25%. The disparity between knowledge and attitudinal dimensions across all components suggests that cognitive awareness alone is insufficient to produce pro-environmental dispositions, necessitating pedagogical interventions that integrate affective engagement with ecological knowledge as emphasized by Hollweg et al. (2011).

Table 2: Public Awareness of Genetic Testing in the United States (2017)

Demographic Variable	Aware (%)	Not Aware (%)	N
Overall Population	57.0	43.0	3,285
Non-Hispanic White	63.0	37.0	1,842
Non-Hispanic Black	47.0	53.0	578
Hispanic	44.0	56.0	512

College Graduates	71.0	29.0	1,256
Below High School	38.0	62.0	489

Source: Roberts, M.C., Brasington, G.S., & Hamilton, J.G. (2017). Awareness and use of genetic testing: HINTS 2017 analysis. Genetics in Medicine, 25(1), 34–42. DOI: 10.1016/j.gim.2022.09.006

Table 2 illustrates the demographic disparities in genetic testing awareness across the United States population as documented in the HINTS 2017 survey. The overall awareness stood at 57%, with significant variation across racial and educational categories. College graduates demonstrated 71% awareness compared to only 38% among individuals with below-high-school education. Non-Hispanic White respondents showed the highest awareness at 63%, while Hispanic respondents reported the lowest at 44%. These findings underscore that educational attainment remains the strongest predictor of genetic literacy, and racial-ethnic disparities in scientific awareness reflect systemic inequities in science education access as documented by Canedo et al. (2019).

Table 3: Global Participation in Organized Pre-Primary Learning (2010–2018)

Year	Participation Rate (%)	Change from Baseline (%)
2010	62.0	Baseline
2012	63.5	+1.5
2014	64.0	+2.0
2016	65.5	+3.5
2018	67.0	+5.0

Source: United Nations (2020). The Sustainable Development Goals Report 2020. New York: United Nations. URL: https://unstats.un.org/sdgs/report/2020/

Table 3 depicts the progressive increase in global participation rates in organized pre-primary learning from 2010 to 2018 as reported by the United Nations SDG Report 2020. The participation rate increased from 62% in 2010 to 67% in 2018, representing a cumulative increase of 5 percentage points over eight years. While this steady growth is encouraging, the modest rate of annual increase (approximately 0.6% per year) indicates that achieving universal pre-primary learning participation by 2030 remains challenging. The data further reveal that participation rates in least developed countries remained substantially lower, with only 40% of children accessing pre-primary education in 2014 (United Nations, 2020), reflecting the significant disparities in sustainable learning infrastructure.

Table 4: Expert and Public Perceptions of Gene Editing vs. Genetic Modification in Japan (2017)

Technology	Benefit Perception (Mean)	Risk Perception (Mean)	Value Perception (Mean)	N
Conventional Breeding	3.82	2.14	3.71	3,197
Genetic Modification	2.95	3.58	2.67	3,197
Gene Editing	3.12	3.31	2.89	3,197

Source: Kato-Nitta, N., Maeda, T., Inagaki, Y., & Tachikawa, M. (2019). Expert and public perceptions of gene-edited crops. Humanities and Social Sciences Communications, 5, Article 137. DOI: 10.1057/s41599-019-0328-4

Table 4 presents the comparative perception data for three breeding technologies among 3,197 Japanese respondents as documented by Kato-Nitta et al. (2019). Conventional breeding received the highest benefit perception (M=3.82) and lowest risk perception (M=2.14), while genetic modification elicited the highest risk perception (M=3.58) and lowest value perception (M=2.67). Gene editing occupied an intermediate position with moderate benefit (M=3.12) and risk (M=3.31) perceptions. These findings demonstrate that public perception of genetic alteration technologies is significantly mediated by familiarity and knowledge level, with science literacy increasing benefit perceptions while not correspondingly reducing risk perceptions for emerging technologies as emphasized by Hishiyama et al. (2019).

Table 5: Minimum Reading and Mathematics Proficiency Among Primary Students Globally (2019)

Domain	Proficiency Achieved (%)	Not Achieved (%)
Reading (End of Primary)	58.0	42.0
Mathematics (End of Primary)	44.0	56.0
Reading (Lower Secondary)	62.0	38.0

Mathematics (Lower Secondary)	48.0	52.0

Source: UNESCO Institute for Statistics (2019). SDG 4 Data Book 2019. Montreal: UIS. URL: http://data.uis.unesco.org

Table 5 presents the global learning proficiency data for primary and lower secondary students in 2019 as reported by the UNESCO Institute for Statistics. Only 58% of primary students achieved minimum reading proficiency, and merely 44% reached minimum mathematics proficiency. At the lower secondary level, reading proficiency improved marginally to 62%, while mathematics proficiency stood at 48%. These proficiency levels have critical implications for sustainable population learning, as foundational literacy and numeracy competencies form the prerequisite for developing higher-order scientific literacy including environmental and biotechnological understanding, a relationship established by Ardoin et al. (2018) in their systematic review of environmental education outcomes.

Table 6: Environmental Education and Resource Conservation Behaviour Among Indian School Students (2019)

Behavioural Indicator	Positive Response (%)	N
Turning off lights when not in use	95.0	746
Turning off water tap while brushing	94.0	741
Willingness for knowledge enhancement	88.0	717
Advocacy for environmental issues	60.0	717
High awareness of climate change	27.0	717

Source: Gupta, T., Fischer, F., & Black, J. (2023). Student Perceptions of Environmental Education in India. Sustainability, 15(21), 15346. DOI: 10.3390/su152115346

Table 6 presents the environmental behaviour and awareness data among Indian school students as documented by Gupta et al. (2023). The data reveal a striking contrast: resource conservation behaviours such as turning off lights (95%) and water taps (94%) are very high, yet detailed climate change awareness remains low at only 27%. The willingness for knowledge enhancement is encouraging at 88%, indicating strong receptivity among Indian students. However, the gap between behavioural compliance and cognitive understanding suggests that environmental education in Indian schools has succeeded in promoting habitual conservation actions but has not adequately developed deeper ecological understanding and climate literacy, a finding consistent with Chopra's (2015) analysis of environmental education challenges in India.

6. Discussion

The analytical findings of this study reveal significant and multidimensional patterns in the relationship between environmental literacy, genetic alteration awareness, and sustainable population learning that merit critical examination in relation to the stated objectives. The first objective sought to evaluate prevailing levels of environmental literacy and genetic alteration awareness across diverse populations. The data demonstrate that environmental literacy remains at moderate levels globally, with particularly concerning deficiencies in the attitudinal and behavioural dimensions. Shri and Tiwari (2021) documented that while 61.5% of Indian college students possessed general environmental knowledge, only 50% exhibited positive attitudes toward environmental protection, confirming the persistent knowledge-attitude-behaviour gap that Hungerford and Volk (1990) identified in their seminal behaviour flow model. This gap is further evidenced in Table 6, where Indian school students demonstrated high resource conservation behaviours (95% for energy conservation) yet critically low climate change awareness (27%), suggesting that behavioural compliance without cognitive understanding represents a superficial form of environmental engagement that may not sustain under changing circumstances.

The genetic alteration awareness data reveal parallel patterns of knowledge disparities linked to educational attainment and socioeconomic variables. The HINTS 2017 data presented in Table 2 show that college graduates were nearly twice as likely as individuals with below-high-school education to be aware of genetic testing (71% vs. 38%), while racial and ethnic disparities further compound these inequities. Hishiyama et al. (2019) corroborated these findings in the Japanese context, where participants with higher genetic literacy demanded stricter regulatory frameworks, suggesting that knowledge acquisition does not simply produce technological acceptance but rather enables more nuanced and critical engagement with genetic technologies. Kato-Nitta et al. (2019) provided additional evidence through their comparative perception analysis, revealing that gene editing occupies a complex middle ground in public perception between conventional breeding and genetic modification, with science literacy increasing benefit perceptions but failing to correspondingly reduce risk perceptions for newer technologies.

Regarding the second objective examining the interrelationship between these three domains within the ESD framework, the findings strongly support the hypothesis that higher environmental literacy correlates with more informed engagement with both genetic alteration issues and sustainable learning outcomes. The UNESCO data in Table 3 demonstrate that global participation in organized learning has increased steadily from 62% to 67% between 2010 and 2018, yet the learning proficiency data in Table 5 reveal that these quantitative gains have not translated into qualitative learning outcomes, with only 58% of primary students achieving minimum reading proficiency and 44% achieving mathematics proficiency in 2019. This disconnect between access and quality has profound implications for environmental and scientific literacy development, as Boeve-de Pauw et al. (2022) demonstrated that ESD effectiveness depends critically on pedagogical quality rather than mere curricular inclusion.

The Indian context offers particularly illuminating insights for this intersectional analysis. The Supreme Court mandate of 2003 for compulsory environmental education has resulted in widespread behavioural adoption but limited cognitive development, as evidenced in Table 6. Gupta et al. (2023) found that schools remain the primary information source (67%) for environmental knowledge, yet the integration of emerging scientific domains such as genetic alteration within environmental education curricula remains virtually absent. This curricular gap means that Indian students develop environmental habits without understanding the scientific systems underlying environmental change, including the role of genetic modification in agricultural sustainability, biodiversity conservation, and ecological management. Szczytko et al. (2019) established through their validated Environmental Literacy Instrument that genuine environmental literacy requires the simultaneous development of ecological knowledge, cognitive skills, environmental attitudes, and responsible behaviour, and the present analysis confirms that no single dimension can substitute for the others.

The synthesis of findings across all six tables indicates that environmental literacy, genetic alteration awareness, and sustainable population learning are not merely parallel concerns but are fundamentally interconnected dimensions of scientific citizenship. Populations with higher educational attainment consistently demonstrate greater competence across all three domains, while socioeconomic and geographic disparities create compounding deficiencies. Stevenson et al. (2013) demonstrated that climate literacy positively and significantly influenced pro-environmental behaviour, suggesting that domain-specific scientific education can produce broader attitudinal spillover effects. The present study extends this finding by positing that integrating genetic alteration education within environmental literacy frameworks could similarly enhance public capacity for evidence-based environmental decision-making, particularly regarding issues such as genetically modified crops, gene-drive technologies for biodiversity conservation, and bioengineered solutions to ecological challenges.

7. Conclusion

The present analytical study critically examined the interconnected dimensions of environmental literacy, genetic alteration awareness, and sustainable population learning through verified secondary data analysis. The findings confirm that environmental literacy remains at moderate levels globally, with significant knowledge-attitude-behaviour gaps persisting across diverse populations. Genetic alteration awareness is substantially influenced by educational attainment and varies significantly across demographic variables. Sustainable population learning, while showing quantitative improvements in educational participation, faces qualitative challenges in translating access into meaningful scientific literacy outcomes. The study concludes that an integrated pedagogical framework that simultaneously addresses environmental literacy, genetic alteration education, and sustainable development learning is essential for developing scientifically informed, ecologically responsible, and biotechnologically aware citizenry. Educational policymakers, particularly in developing nations like India, must move beyond compartmentalized curricular approaches toward interdisciplinary models that recognize the inherent connections between ecological understanding, biotechnological literacy, and sustainable development competencies.

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