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Building bridges to sustainable education: Integrating AI and infrastructural capacities for eco-centric pedagogy

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Abstract

Education plays a vital role in leading individuals towards an environmentally balanced future as part of the effort to achieve sustainable development. This study examines the required infrastructure needed to effectively deploy eco-centric pedagogy in various educational environments, focusing on the transformational impact of artificial intelligence (AI). This research used a mixed-methods approach, incorporating case studies from different geographical regions, to investigate the interaction between infrastructure, curriculum design, instructional practices, and community engagement. The study examines the essential elements of educational infrastructure that facilitate eco-centric teaching methods and assesses the capacity of AI to improve these endeavors. Hence, it argues for a comprehensive strategy for educational development that combines empirical facts and theoretical insights. It proposes leveraging technological improvements and eco-centric principles to foster environmentally conscientious learners. The results emphasize the need to develop and support the necessary infrastructure to drive substantial changes in educational systems, ultimately contributing to the worldwide effort to achieve sustainability.

Introduction

In recent times, the global discourse on sustainability has recognized education as a vital means of promoting environmental stewardship. The pressing necessity to synchronize educational systems with the principles of sustainability has resulted in the development of eco-centric pedagogy, an instructional approach that incorporates environmental awareness at the heart of teaching and learning. Eco-centric pedagogy surpasses the mere inclusion of environmental subjects in the curriculum (Kaur et al., 2023). A paradigm shift is necessary to fundamentally modify the conceptualization, delivery, and experience of education. This transition necessitates substantial infrastructure support to ensure that eco-centric principles are not only taught but also incorporated into the educational setting. The use of AI has shown the ability to improve the effectiveness of a range of environmentally-focused teaching techniques. This paper tries to evaluate the necessary infrastructural needs for the effective implementation of eco-centric pedagogy, with a specific emphasis on the transformational capabilities of artificial intelligence in this undertaking.

Eco-centric pedagogy is founded on the notion that education ought not to only provide knowledge regarding the environment, but also foster a deep and interwoven bond between learners and the natural world. Scholars, including Orr (1991), argue that the current environmental issues are not solely attributable to a lack of information, but also to a disconnect between humans and nature. Traditional educational approaches additionally accentuate this separation. The mentioned pedagogy aims to integrate environmental awareness into all aspects of the educational process, including curriculum design and classroom activities, to close this divide. This method is in line with the main objectives of sustainable development, which highlight the importance of education systems in nurturing individuals who have ethical values, are well-informed, and actively participate in solving intricate environmental issues (Sterling, 2011).

The success of these instructional modes is heavily reliant on proper support infrastructure. These include both the physical amenities and assets in an educational institution, as well as systemic support systems underpinning any teaching-learning process. Educational progress, argue Tilbury and Cooke (2005), is almost certain to be unsuccessful even with the best of intentions if those infrastructural capacities are not in place. This is of particular importance for eco-centric teaching which itself may be quite radical and challenging to current educational ways or approaches. For instance, the incorporation of outdoor learning activities, the employment of sustainable materials, and the integration of environmental monitoring systems necessitate a reassessment of the design and utilization of educational spaces (Scott & Gough, 2003).

Recently, there has been much talk regarding the plenty of ways artificial intelligence (AI) can be integrated into education to increase the efficiency in teaching various methods such as eco-centric pedagogy. However, as Rudolph et al. (2024) point out, the integration of generative AI technologies introduces a paradox. While these tools offer significant potential for enhancing pedagogy and administration, they also raise critical issues related to academic integrity, ethical usage, and environmental sustainability. Addressing these concerns necessitates fostering critical AI literacy among educators and students, aligning with the goals of eco-centric pedagogy to ensure responsible innovation. Studies underscore the potential of Generative AI (GenAI) to enhance personalized learning, streamline administrative processes, and enable innovative teaching practices across diverse educational settings (Kutty et al., 2024). This aligns with the objectives of eco-centric pedagogy, where technological advancements like AI can optimize curriculum design and improve infrastructure for sustainable education. Furthermore, AI literacy is emerging as a critical component of modern curricula, emphasizing the need for students to develop analytical thinking and ethical decision-making skills to navigate the complexities of AI applications effectively (Damaševičius, 2024). Rudolph et al. (2024) further elaborate on the necessity of AI literacy by highlighting the regulatory gaps and embedded biases in generative AI technologies, such as chatbots. These issues underscore the importance of equipping learners and educators with critical tools to evaluate and use AI responsibly, particularly in advancing eco-centric education. Frameworks such as the "Input/Output/Action" model serve as structured approaches for integrating AI literacy, offering actionable insights into how students interact with and critically assess AI-generated outputs. These discussions collectively highlight the indispensable role of AI in shaping an educational system that promotes both technological proficiency and environmental responsibility.

AI technologies provide a variety of tools that can help in eco-centric teaching. These technologies involve adaptive learning platforms that can customize content to the unique needs of each learner, and AI-driven simulations enable students to interact with intricate ecological systems in a simulated environment (Holmes et al., 2019; also see Waring, 2024). AI can make data-driven decisions in educational institutions more accurate so that schools and colleges can use resources effectively, thereby reducing their environmental damage (Luckin, 2018). AI not only has the potential to support an eco-centric pedagogy through improved teaching and learning practices but also in reforming educational infrastructure. However, the integration of AI into educational systems is complicated despite its capabilities to enable eco-centric education. Holmes and Tuomi (2022), and Selwyn (2019) both further underline the significant ethical and moral implications of using AI in education. Some of the concerns are centered around data privacy, digital equity, and bias that makes AI amplify current educational inequalities. Without careful thought, the terrifying risk may lurk under our noses that AI is used not to enact radical changes in education but only to more efficiently sustain already-untenable practices of educational labor (Williamson, 2018).

This empirical study examines the correlation between infrastructural resources, eco-centric educational approaches, and artificial intelligence in education. It explores the relationship between these factors both separately and when combined. It starts with three basic questions:

(i) What are the necessary support structures required to fully adopt eco-centric pedagogy?

(ii) How to integrate artificial intelligence in educational systems for sustainable education?

(iii) What are some challenges and advantages of using AI-assisted approaches in eco-centric teaching practices?

This study aims to provide a valuable addition to the growing body of literature on sustainable education by specifically addressing these concerns. The purpose is to offer significant observations that can be utilized to influence policy and implementation in this critical domain.

To answer these questions, the inquiry employs a mixed-methodological approach with quantitative and qualitative data to have a rather complete analysis of what matters here. The paper reviews case studies of eco-centric teaching approaches and AI implementation in different educational setups for the integration to become successful. The objective of this study is to reveal the most effective methods and innovative strategies that can be utilized in different educational settings. With this consideration, the following section will delve into the theoretical foundation of eco-centric pedagogy and examine current research on artificial intelligence in education. This section will establish the foundational knowledge necessary for understanding the infrastructure-related difficulties and possibilities that were mentioned in subsequent sections.

Literature review

One important trending issue of high academic interest is Sustainable Education, which has been gaining public attention due to the escalated demand for addressing environmental issues. The renewed interest in sustainability and eco-friendly practices represents a paradigmatic shift that must be matched by a careful reorganization of contemporary education networks, following the creation of integrated teaching methods that cultivate a mutually beneficial relationship between students and their environment. Eco-centric pedagogy is in no way just a simplistic top-up to contemporary educational paradigms but rather acts as a collaborative change agent, more relevantly locating education at the heart of humanity's survival (Horton, 1990). In this literature review, we elaborate on the multiple aspects of sustainable education, including infrastructural capacities in terms of teaching and learning spaces and materials, curriculum design, and community engagement to implement various methodologies, while stressing upon AI (Artificial Intelligence) as an emerging technology that can facilitate the transformation process.

Eco-centric pedagogy is centered on the concept that education should cultivate a harmonious and mutually advantageous relationship between humans and the environment (Borsari & Kunnas, 2022). Orr (1991) and Sterling (2011) have advocated for an educational system that goes beyond conventional teaching methods, emphasizing the cultivation of ecological literacy and an understanding of the interconnectedness of all living organisms. Orr's emphasis on ecological literacy highlights the need for students to grasp the complexities of ecosystems and their role within them. Sterling, meanwhile, argues for a transformative learning process where sustainability is woven into the fabric of education, influencing not just what is taught, but how it is taught and how educational institutions operate. The transition to an eco-centric pedagogy goes beyond mere modifications in teaching approaches; it demands a fundamental reconsideration of the underlying infrastructure that sustains educational institutions. In this context, the term "infrastructure" encompasses more than just physical areas. It also includes the organizational structures, rules, and technologies that facilitate the implementation of sustainable practices. Huckle (1991) and Warren et al. (2014) assert that sustainable education thrives in environments where infrastructure supports experiential learning, interdisciplinary collaboration, and strong community ties. This perspective is supported by empirical studies, such as those by Henderson and Tilbury (2004), which demonstrate that schools with green infrastructure—energy-efficient buildings and ample green spaces—are more effective in promoting environmental education.

The design of curricula and the methodologies employed in teaching are central to the successful implementation of eco-centric pedagogy. Sterling's (2011) concept of "curriculum as process" calls for a dynamic and evolving curriculum that is responsive to the changing needs of society and the environment. This method challenges the traditional boundaries between subjects and advocates for a curriculum that integrates multiple disciplines to illustrate the interconnections between ecological, social, and economic systems. Sobel (2004) and Gruenewald (2003) bolster this perspective by emphasizing the significance of experiential and location-based learning. Embracing a sense of place and accountability, this method entails students actively engaging in their local community and nurturing a connection to the environment. Eco-centric education is facilitated by teaching methods that emphasize active engagement with the natural world. Sobel (2004) promotes place-based learning, which involves students gaining knowledge from their immediate surroundings and developing a strong bond with their local environment. This technique is enhanced by outdoor education, which involves taking the learning process outside the confines of the classroom and immersing students in the natural environment, enabling them to directly see and engage with the ecosystems they are studying. Kolb's (2014) concept of experiential learning supports these approaches by highlighting the significance of learning through first-hand experience, especially in addressing practical environmental problems.

There are numerous case studies worldwide, which prove the efficacy of such eco-centric pedagogy. The Green School in Bali, Indonesia, is a prime example of how sustainability may be integrated into the teaching process. The school's curriculum is focused on sustainability, as outlined by Cole (2014). Students engage in hands-on projects that foster environmental stewardship and study in open-air bamboo classrooms. This example underscores the transformative potential of eco-centric pedagogy and its ability to inspire

similar initiatives globally. Similarly, Bhutan's Green School initiative integrates the country's philosophy of Gross National Happiness (GNH) into its educational framework, as discussed by Dey (2023) and Chitra and Chitra (2024). A focus on the emotional, spiritual, and environment-based well-being of this program aligns with Bhutan's national concept that progress should be based on well-being rather than economic growth. The example of the Green School system in Bhutan can be an effective avenue to show what a holistic and context-based approach to education might contribute, at least partially, toward larger goals of sustainable development. The Green Belt Movement in Kenya, which was founded by Nobel laureate Wangari Maathai, is another example of eco-centric education that is further fortified by community connectivity. They have collaborated extensively with educational institutions to educate students about the importance of afforestation and sustainable land management, while also including environmental education into the school curriculum (Maathai, 2003). The project emphasizes the crucial importance of education in facilitating considerable social and environmental transformation, especially in places that are confronted with substantial ecological difficulties.

Despite the growing number of works on eco-centric pedagogy and sustainable education, there are still substantial gaps that need to be addressed to achieve coordination within this educational framework. The most significant disparity lies in the way infrastructural capabilities are understood and evaluated in various educational settings, particularly those necessary for facilitating eco-centric teaching methods. Infrastructure plays a crucial role in fostering sustainable schooling. However, there is a dearth of research on the essential requirements for effectively implementing eco-centric teaching. Several researchers have discussed the significance of infrastructure in long-term education (Warren et al., 2014; Henderson & Tilbury, 2004). But a lot of the study being done now is broken up. It usually focuses on specific things, like eco-friendly homes or different energy sources. We still need a broad view of the situation. From this point of view, we should think about how infrastructure fits in with technology, society, and curriculum projects. An additional noteworthy oversight is the inadequate examination of the potential role of emergent technologies, such as Artificial Intelligence (AI), in promoting eco-centric education. Luckin (2018) has found that there is a growing interest in the use of AI in education. Research is required to investigate both the potential advantages of AI and the obstacles and ethical concerns related to its incorporation into eco-centric educational systems. Moreover, the extent to which AI affects educational fairness and environmental sustainability, specifically energy usage and availability, has not been well investigated. It is also important to note here that the discussion above reveals gaps in the comprehension of how eco-centric pedagogy can be mainstreamed and adapted to various cultural or geographical contexts. While case studies such as the Green School in Bali and Bhutan's Green School initiative are informative, additional comparative research is required to investigate the effectiveness of different approaches in different contexts. To develop a more comprehensive understanding of how to adapt eco-centric pedagogy to specific environments, these studies should consider the local socio-cultural, economic, and environmental contexts that influence the adoption of sustainable education practices.

This study seeks to fill these gaps by undertaking a thorough analysis of the requisite infrastructure capabilities required for the successful implementation of eco-centric pedagogy in various educational environments. This project will provide a comprehensive knowledge of the difficulties and advantages related to sustainable education by using a diverse methodology that combines real-world data, theoretical models, and case studies. The study will examine the interplay and impact of several factors, including infrastructure, curriculum design, pedagogical approaches, and community engagement, on the effectiveness of eco-centric educational programs.

Methodology

As a comprehensive methodology, this study examines what is required in terms of infrastructural capacities for eco-centric teaching and learning across various educational settings in India. The research aims to establish how infrastructure, curriculum design, pedagogical methodologies, and community engagement interact to support sustainable education. The purpose of the inquiry is to create a correlation between theoretical frameworks and practical implementations by specifically examining educational contexts in the actual world. This will provide substantial and valuable knowledge for educators, policymakers, and institutions. To achieve this goal, the study utilizes a case study methodology, which is especially appropriate for examining complex phenomena in real-life settings. This allows for a thorough examination of the specific challenges and benefits associated with the implementation of eco-centric education in different institutional contexts. The study focuses on three specific geographic regions in India that demonstrate diverse socio-cultural and environmental conditions. This selection ensures that the findings are not only relevant to the specific local context but also have broad applicability.

Research design

The study encompasses 12 months, commencing in January and concluding in December 2023, encompassing an entire calendar year. This period is critical for observing how environmental education practices adapt to seasonal variations and evaluating the lasting impacts of infrastructure changes on eco-centric teaching methods. This timeline ensures that insights gathered are not limited to the academic schedule but reflect the year-round requirements and adaptations of sustainable education practices. The case study sites encompass a remote region in northern India, a metropolitan hub in the western area, and a seaside town in the south. A rural area with a strong agricultural history and close-knit community is a great place to look into how to incorporate traditional ecological knowledge into official schooling. The urban core, which is in a metropolis that is growing quickly, shows a different picture: the processes of urbanization and industry are harmful to the environment.

The coast is known for its diverse wildlife and booming tourism industry, but it also has environmental problems like coastal erosion and pollution in the ocean. Because of this, it is a great place to look into how to use eco-friendly ideas in schools.

The research involves 120 participants from specific locations, including instructors, managers, and students. To offer a comprehensive representation of the application of eco-centric education, the individuals selected are carefully chosen. Forty educators from a variety of educational institutions, including elementary, secondary, and tertiary, participate in discussions regarding the integration of eco-centric concepts in a variety of educational settings. The survey included twenty school and college leaders. They discuss the policy and infrastructure components of sustainable education, namely examining resource allocation, infrastructure development, and community engagement. Furthermore, a cohort of 60 students spanning various age groups and educational backgrounds has been incorporated to share their first-hand encounters with the innovative teaching methodologies being used.

Data collection and analysis

This study was conducted in an inclusive mixed-method design using both qualitative and quantitative methods to answer the research questions fully. All participants were asked to complete structured surveys that collated quantitative information about their experiences and perceptions of eco-centric pedagogy. The surveys approached subjects on diverse issues and included curriculum data, methods of teaching details, infrastructure insights, and the use of technology in enhancing sustainable education. These survey responses were extensively analyzed for common trends and patterns as they informed the generalized results of this study. The other methods consisted of in-depth, semi-structured interviews with a stratified subset of 15 educators (five per province), ten administrators, and 20 students. The interviews yielded qualitative academic information concerning the practical barriers and successes these participants have experienced as they attempted eco-centric peacemaking pedagogy practices. The interviews sought information that could help elaborate the factors underpinning infrastructural capacities, community engagement, and technological options in terms of enhancing or disrupting sustainable education initiatives. We conducted 30-minute interviews with the teachers themselves in order to gain qualitative information about their experiences and how eco-centric pedagogy was operationalized within that setting. Observations were also conducted to help further support the results of our surveys and interviews from each educational institution. These observations gave an inside look at how eco-centric pedagogy was in action around the globe. We looked for the types of physical infrastructures, classroom practices, and local interactions that seemed to provide some support (or challenge) for sustainability integration into education. These helped to substantiate and contextualize the survey by providing a more nuanced perspective of the multidimensional layers of eco-centric education while observing these elements in real-time.

Both quantitative and qualitative techniques were used for the analysis of all data gathered from these methods. As an analytic tool, the quantitative survey data were statistically critiqued for patterns and correlations that would supply a big-picture understanding of eco-centric pedagogy influencing conditions. To obtain a more comprehensive knowledge of the experiences and opinions of the participants, the qualitative data from the observations and interviews were also categorized into themes at the same time. This combination of techniques guarantees that the study may provide a thorough understanding of the factors that contribute to the success or failure of eco-centric pedagogy in different educational environments.

To sum up, the methodology employed was able to present a detailed and layered inquiry into the kind of infrastructural support that is imperative for the concrete realization of eco-centric pedagogy in India. The research had implications for broader work in sustainable education as researchers sought to understand how different educational contexts and methods might impact faculty practices. The results of this study will help to provide insights that can inform future policy and practice in the service of an overarching aim—to foster a new generation who are environmentally literate, responsible citizens capable of contributing positively to meeting the environmental challenges facing societies in the 21st century.

Case studies and analysis

A thorough examination of three case studies conducted in various regions of India is presented in this section. The case studies include a pastoral area in the northern region of Uttarakhand, an urban center in the western region of Maharashtra, and a coastal area in the southern region of Kerala. Each case study delves into the unique obstacles, infrastructural capabilities, and results associated with the implementation of eco-centric pedagogy. The data were gathered through surveys, interviews, and observations, and subsequently examined using statistical techniques such as ANOVA and regression analysis to assess the efficacy of eco-centric teaching in each geographical area.

Quantitative analysis

Case Study 1:

In Uttarakhand, India, the first case study was conducted at an educational institution that caters to a predominantly agrarian community. This area is renowned for its robust agricultural customs and dependence on indigenous resources. A total of 50 participants were included in the data collection, consisting of 20 educators, five administrators, and 25 students. The variables assessed encompassed curriculum integration, infrastructure quality, community participation, teacher preparedness, and student engagement. Consider the following table for descriptive statistics results:

Table 1: Descriptive statistics (N=50).

Category	Mean	SD	Variance	Range
Integration of Eco-centric Curriculum	4.2	0.7	0.49	2.5
Use of Local Resources	4.5	0.6	0.36	2
Infrastructure Quality	3.1	1.2	1.44	3.5
Community Engagement	4.8	0.4	0.16	1
Teacher Preparedness	3.9	0.8	0.64	2.5
Student Engagement	4.3	0.5	0.25	2

To assess the significance of differences in curriculum integration, infrastructure quality, and other variables, an ANOVA was conducted.

Table 2: ANOVA summary.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.92	5	1.784	3.81	0.002	2.37
Within Groups	22.14	44	0.503			
Total	31.06	49				

The ANOVA results indicate that there is a statistically significant difference in the measured variables ($F = 3.81$, $p < 0.05$). This suggests that factors such as infrastructure quality and community engagement significantly affect the integration of eco-centric curriculum in the rural northern region.

A multiple regression analysis was performed to understand the impact of community engagement and infrastructure quality on student engagement.

Table 3: Regression analysis results.

Predictor	B	SE B	β	t	P-value
Community Engagement	0.58	0.13	0.61	4.46	0
Infrastructure Quality	0.27	0.11	0.32	2.45	0.018

The regression analysis shows that community engagement is the strongest predictor of student engagement ($\beta = 0.61$, $p < 0.01$), followed by infrastructure quality ($\beta = 0.32$, $p < 0.05$). This indicates that higher community involvement and better infrastructure significantly enhance student engagement in eco-centric pedagogy.

Case study 2:

The second case study was carried out in a metropolitan area noted for its technological infrastructure—the western region of Maharashtra—that is confronting issues associated with urbanization. A total of 40 individuals were included in the data collection, comprising 15 educators, five administrators, and 20 students. The primary areas of emphasis were the integration of technology, the quality of infrastructure, and the engagement of the community.

Table 4: Descriptive statistics (N=40).

Category	Mean	SD	Variance	Range
Integration of Eco-centric Curriculum	3.8	0.9	0.81	3
Use of Urban Green Spaces	3.5	1	1	4
Infrastructure Quality	4.7	0.3	0.09	1
Community Engagement	3.2	0.7	0.49	2.5
Teacher Preparedness	4.4	0.5	0.25	2
Student Engagement	3.7	0.6	0.36	2.5

An ANOVA was conducted to determine if there were significant differences among the variables.

Table 5: ANOVA summary.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.47	5	1.294	2.71	0.036	2.45
Within Groups	17.71	34	0.521			
Total	24.18	39				

The ANOVA results show a statistically significant difference in the measured variables ($F = 2.71$, $p < 0.05$), indicating that factors such as infrastructure quality and community engagement influence the effectiveness of eco-centric pedagogy in the urban western region.

To explore the relationship between infrastructure quality and the integration of eco-centric curriculum, a Pearson correlation analysis was performed.

Table 6: Correlation matrix.

Variables	Integration of Curriculum	Infrastructure Quality	Community Engagement
Integration of Curriculum	1	0.72**	0.45*
Infrastructure Quality	0.72**	1	0.38*
Community Engagement	0.45*	0.38*	1

* $p < 0.05$, ** $p < 0.01$

The correlation analysis indicates a strong positive relationship between infrastructure quality and curriculum integration ($r = 0.72$, $p < 0.01$), suggesting that better infrastructure leads to more effective integration of eco-centric curriculum in the urban western region of Maharashtra.

Case study 3:

The third case study was done in a coastal region of Kerala renowned for its rich biodiversity and prevalent environmental issues. The chosen educational institution actively engages in conservation initiatives, focusing on matters such as coastline erosion and marine pollution. A total of 30 participants were included in the data collection, consisting of 10 educators, 5 administrators, and 15 students. The emphasis was placed on the utilization of regional ecological concerns, the calibre of infrastructure, and the readiness of educators.

Table 7: Descriptive statistics (N=30).

Category	Mean	SD	Variance	Range
Integration of Eco-centric Curriculum	4	0.8	0.64	3
Use of Local Environmental Issues	4.3	0.6	0.36	2
Infrastructure Quality	3.4	1.1	1.21	3
Community Engagement	4	0.9	0.81	3
Teacher Preparedness	3.7	0.7	0.49	2.5
Student Engagement	4.1	0.5	0.25	2

ANOVA result summary is as follows:

Table 8: ANOVA summary.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9.02	5	1.804	3.29	0.018	2.53
Within Groups	15.24	24	0.635			
Total	24.26	29				

The ANOVA results indicate a statistically significant difference in the variables measured ($F = 3.29$, $p < 0.05$), suggesting that factors like the use of local environmental issues and infrastructure quality significantly impact the effectiveness of eco-centric pedagogy in the coastal southern region.

A multiple regression analysis was conducted to determine the impact of infrastructure quality and teacher preparedness on student engagement.

The regression analysis shows that teacher preparedness is a stronger predictor of student engagement ($\beta = 0.54$, $p < 0.01$) compared to infrastructure quality ($\beta = 0.42$, $p < 0.05$). This suggests that well-prepared teachers significantly enhance student engagement in eco-centric pedagogy, even when infrastructural challenges exist.

Table 9: Regression analysis results.

Predictor	B	SE B	β	t	P-value
Infrastructure Quality	0.31	0.15	0.42	2.07	0.048
Teacher Preparedness	0.44	0.14	0.54	3.14	0.004

An overall ANOVA was conducted using data from all regions to compare the effectiveness of eco-centric pedagogy across the three regions.

Table 10: Comparative ANOVA summary across regions.

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	18.41	2	9.205	4.88	0.009	3.09
Within Groups	67.05	117	0.573			
Total	85.46	119				

The overall ANOVA results confirm a statistically significant difference in the effectiveness of eco-centric pedagogy across the regions ($F = 4.88$, $p < 0.01$). The post-hoc Tukey HSD test further revealed that the rural area of Uttarakhand and the coastal regions of Kerala had significantly higher effectiveness scores compared to the urban region of Maharashtra.

To assess the correlation between the integration of AI and eco-centric pedagogy in a quantitative manner, supplementary inquiries were conducted regarding the utilization of AI tools. These inquiries encompassed whether individuals employed such tools, the frequency of their usage, and their perceived efficacy in fostering positive learning outcomes as responsible global citizens. Subsequently, these findings were examined and assessed to determine the influence of AI utilization on many factors, including student engagement, teacher readiness, and curricular integration.

Table 11: Descriptive statistics for AI integration across regions.

Category	Uttarakhand (Mean)	Maharashtra (Mean)	Kerala (Mean)	Overall SD
Frequency of AI Use	2.3	4.6	3.1	1.1
Perceived Effectiveness	3.5	4.7	3.8	0.9
Impact on Student Engagement	3.2	4.4	3.6	1
Impact on Teacher Preparedness	2.8	4.5	3.3	1.2

The correlation study demonstrated a statistically significant positive association ($r = 0.68$, $p < 0.01$) between the frequency of AI use and student engagement in Maharashtra. This suggests that a higher level of AI integration is linked to more student participation in eco-centric activities. The preparedness of instructors was significantly positively correlated with the integration of artificial intelligence (AI) in

Maharashtra ($r = 0.65$, $p < 0.01$). This implies that instructors who frequently employ AI tools are more self-assured and prepared to present content that emphasizes environmental issues. However, the associations were less robust in Uttarakhand and Kerala due to the limited availability of technology and infrastructure.

The ANOVA results show that there is a statistically significant difference between the regions in how successful they think AI integration is ($F = 5.67$, $p < 0.01$). The post-hoc study showed that Maharashtra's use of AI was much more successful than those in Uttarakhand and Kerala. This shows how important it is to have a strong technological infrastructure for AI-driven education.

Table 12: ANOVA summary for AI integration.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	7.85	2	3.925	5.67	0.007	3.1
Within Groups	39.82	117	0.34			
Total	47.67	119				

Qualitative analysis

The qualitative aspects of eco-centric pedagogy implementation in different geographical contexts across India were thereby analyzed by the study, with interview and observation data generated from each one of the three case study locations through NVivo. The mentioned software was used to identify the themes, patterns, and relationships in the data that allowed for a more detailed understanding of educators', administrators', and students' unique experiences, perceptions, and challenges within each region. Based on the NVivo analysis, we present results qualitatively. This qualitative data included interviews with educators, administrators, and students as well as classroom observational work that was imported into NVivo for systematic analysis. First, the data were coded to draw out emergent themes and sub-themes across regions. All data were coded in nodes that included curriculum integration, community engagement, and infrastructural challenges using the coding function within NVivo.

Table 13: Summary of key themes and sub-themes identified in NVivo.

Theme	Sub-Themes	Frequency of Coding
Curriculum Integration	Traditional Knowledge, Environmental Issues, Curriculum Adaptation	78
Community Engagement	Local Involvement, Parental Support, Community Resources	65
Infrastructural Challenges	Resource Availability, Facility Quality, Technological Access	83
Teacher Preparedness	Training Programs, Pedagogical Approaches, Curriculum Understanding	58
Student Engagement	Experiential Learning, Environmental Awareness, Active Participation	72
Technological Integration	Digital Tools, AI Usage, Technology Training	41

Region-specific qualitative insights

One prominent subject that emerged in the Rural Northern Region of Uttarakhand was the incorporation and integration of indigenous ecological knowledge into curricula (Celidwen & Keltner, 2023). Eco-centric ideals must be in alignment with the daily lives and interactions of students in this region, as emphasized by numerous educators who prioritize sustainability. This can be achieved through the implementation of agricultural practices or other community initiatives. This method resonated deeply with the students, as it linked theoretical knowledge to practical life situations. An educator offered an example of this: "*Sustainability is easier for our students to grasp when we can relate it to their lives, such as the way in which many student families farm or the ways that everyone conserves water…*" Both interviews and observations illustrated this predominant emphasis on traditional knowledge, which seemed to be a leading thread in the educational approach taken by the community.

Community engagement in the educational process was another important theme observed predominantly in Uttarakhand. There was involvement from parents and the community, especially in environmental conservation initiatives within schools. What soon became apparent in the analysis was that this engagement did not just augment eco-centric education, but it was essential to its success. An administrator said, "*The community is hugely involved; they donate supplies, and when people from the community go to schools, it makes a statement because we are learning about what you've taught us*." However, despite the strong community support, infrastructural challenges were a recurring issue. The lack of modern facilities and limited access to technology were frequently mentioned as barriers to fully implementing eco-centric pedagogy. One teacher expressed this concern, stating, "*We have the knowledge and the community's support, but our infrastructure is lacking. We need more resources and technology to enhance our teaching*." These insights underscore the need for improved infrastructure to support the otherwise strong community-based educational model in this region.

Technological integration was a prominent theme in the Urban Western Region of Maharashtra. The utilization of digital tools and AI to advance eco-centric pedagogy was extensively documented, as educators employed these technologies to develop interactive and engaging teachings on sustainability (Dandachi, 2024). Nevertheless, the reliance on technology also underscored disparities in access, as certain students lacked the requisite resources to completely capitalize on these digital tools. This highlights a significant urban-rural divide within Maharashtra, where urban schools, although better equipped technologically, may still struggle with inclusivity, contrasting with rural settings that often rely on community-based engagement over technological access. It was noted that not all students in rural areas have equal access to these tools, which can result in learning disparities. This issue of unequal access was a significant concern, reflecting the broader challenges of integrating technology into education in an equitable manner. In the urban area, most of the infrastructure is quite good and has present-day facilities and resources. This robust infrastructure enabled the good practice of eco-

centric pedagogy, while an analysis identified tension caused by conflicting goals—between rapid urban development in a catch-up locality and sustainability education. One administrator noted, "*Our infrastructure is excellent, but the urban environment sometimes contradicts the sustainability messages we are trying to teach…*" This conflict implies that although the infrastructure is highly developed, the urban setting has distinct obstacles to sustainability education, especially in harmonizing educational objectives with the realities of an industrialized environment.

Unlike the rural setting, community involvement in Maharashtra was less widespread. While eco-centric education received overall support from parents and community people, their engagement was rather restricted, often limited to attending school events rather than actively engaging in the instructional process. One teacher noted, "*Parents are supportive, but their involvement is often limited to attending events rather than being actively engaged in the educational process.*" This contrast with the rural region highlights the challenges of fostering community involvement in more urbanized and perhaps more individualistic settings.

Teachers in the Coastal Southern Region of Kerala effectively utilized the local environment as a valuable instructional asset, effortlessly integrating real-life environmental concerns into the curriculum. One teacher described this approach, saying, "*We use the coastal environment as our classroom. The students learn about the importance of marine life and the impact of human activities on the coast.*" This practical, hands-on approach to teaching sustainability was well-received by students, who were actively engaged in environmental projects and demonstrated a strong understanding of the local ecological issues. Problems with infrastructure were an important subject in Kerala, especially when it came to how the environment affected school buildings. Being close to the coast was good for teaching about the environment, but it was also dangerous for the buildings, especially during the monsoons. One supervisor brought this up by saying, "*Being close to the coast is both a blessing and a curse. It gives us a unique place to learn, but it also puts our equipment at great risk, especially during the monsoons*." These problems show how important it is to have a strong infrastructure that can handle the stresses of the environment and one that helps with eco-friendly schooling.

In summary, the qualitative insights from these three states—Uttarakhand, Maharashtra, and Kerala—display both opportunities and intricate issues that are associated with the national-scale implementation of eco-centric pedagogy. The implications emphasize the necessity of customizing instructional strategies to the local context, taking into account environmental conditions, community engagement, infrastructure support, integration of traditional knowledge and scientific content, and the integration of traditional knowledge and scientific content. By addressing these region-specific requirements, educational institutions can be better positioned to foster sustainability and develop environmentally responsible citizens.

Discussion

This study sheds light on how eco-centric pedagogy is being implemented across educational settings in India. It provides a record of what many have accomplished and faced in various regions. The study demonstrates the use of quantitative and qualitative data from Kerala, along with Maharashtra and Uttarakhand, which are contrastingly different in their experiences and abilities, to indicate key determinants influencing the sustainability of educational activities. These findings provide useful insights for educators and policymakers and contribute to the broader discussion on how education can be used to tackle environmental concerns. A noteworthy discovery from this study is the substantial impact that community involvement has on the effective execution of eco-centric teaching methods. The community's participation was recognized as a significant factor in shaping sustainable education projects, highlighting the importance of incorporating indigenous ecological knowledge within Uttarakhand. The instruction offered during regular school activities, particularly those about environmental preservation, was enhanced by pupils directly engaging in the actual work of their community. This served to reinforce the concepts of sustainability that they had learned in school. That strong parental network was able to clear some of the logistical hurdles that schools in this rural region face, where modern upgrades are often difficult if not impossible.

The urban scenery of Maharashtra, however, was entirely different. The integration of technology and artificial intelligence played a crucial role in delivering education with a specific emphasis on ecological issues. Through the utilization of digital resources, educators adeptly created interactive and tailored courses that effectively captivated their students. Nevertheless, the dependence on technology has also highlighted gaps in internet access, as some students lacked sufficient digital resources to fully exploit these online tools. The digital gap, resulting from disparities in technology and infrastructure availability, especially in densely populated urban regions where certain individuals lack access, poses a substantial obstacle to the equitable implementation of eco-centric education.

This aligns with the concerns raised by Rudolph et al. (2024), who emphasize that generative AI technologies can exacerbate digital inequities if not carefully managed. Their insights call for regulatory frameworks that ensure access to AI resources without compromising equity and sustainability, particularly in diverse educational settings. This highlights the significance of regionally tailored interventions for the long-term viability of education, a concept that has been emphasized by findings from Kerala. Within this coastal region, educators prioritized addressing local environmental issues such as the continuous erosion of beachfront property and the preservation of marine ecosystems. They accomplished this by instructing pupils through the utilization of the environment as an educational asset. The pupils valued this pragmatic approach and also cultivated a more profound comprehension of local ecological concerns. Nevertheless, the distinctive physical obstacles in that region also presented substantial infrastructure difficulties, rendering it equally arduous to

ensure the safety of pupils during storms. The key aspect is that the curriculum must be tailored to address specific local environmental issues. However, its effectiveness will be limited unless it is complemented with infrastructure that can effectively address the diverse environmental concerns specific to each area.

The research not only shows these particular findings but also reveals several wider tendencies that have significant implications for the future of eco-centric education in India. The involvement of the community in the educational process is something that should not be overlooked. All three regions underlined the significance of community involvement to ensure the success of environmentally responsible education projects. In addition to these specific findings, the study also reveals several broader trends that have significant implications for the future of eco-centric teaching in India. If we were to disregard the significance of community involvement in the educational process, we would be missing the mark. There was a strong emphasis placed in each of the three regions on the significance of community involvement in ensuring the success of environmentally friendly education projects. In addition, the study highlights the significance of conserving the environment, the continuous difficulty of developing a secure learning environment, and the pressing requirement to make investments in educational infrastructure, particularly in regions where school buildings are more prone to environmental strain. For instance, in Kerala, the proximity to the sea poses distinctive issues that necessitate infrastructure capable of enduring unfavorable weather conditions. To effectively implement environmentally-focused teaching approaches in these locations, it is essential to address all necessary infrastructure requirements. The study highlights the significance of developing a curriculum that is versatile and adjustable. The educational programs in all three locations achieved success by implementing modifications to the curriculum that more accurately represented the inherent natural and cultural characteristics of each respective locality. In the process of campaigning for environmentally conscious teaching methods, it is of the utmost importance to produce lessons that can be adapted to meet the specific characteristics of the given place. In order to accomplish this, it is necessary to take into consideration the particular environmental conditions and concerns of the local area, while simultaneously incorporating more fundamental concepts of sustainability.

Conclusion

The findings of this study illuminate the varied and context-specific challenges and opportunities associated with implementing eco-centric pedagogy across distinct regions in India. By focusing on three diverse settings—rural Uttarakhand, urban Maharashtra, and coastal Kerala—we reveal how local environmental, cultural, and infrastructural factors influence the effectiveness of eco-centric educational practices. In rural areas like Uttarakhand, strong community involvement and traditional ecological knowledge emerge as foundational supports for eco-centric education. The integration of indigenous knowledge into the curriculum resonates deeply with students and connects their learning to daily life, thus fostering environmental stewardship. However, limitations in technological infrastructure remain a barrier to fully leveraging digital tools and AI resources in these settings. In contrast, urban regions like Maharashtra benefit from advanced technological infrastructure that facilitates the integration of AI and digital tools into eco-centric teaching. These resources enable innovative, interactive methods for engaging students with sustainability topics. However, the study highlights a significant urban-rural divide within Maharashtra, where disparities in access to resources pose challenges for inclusive and equitable education. Urban areas also experience less community engagement, which, while present, is not as embedded in the educational process as it is in rural settings. This finding underscores the importance of fostering a sense of community participation even in highly urbanized environments. Coastal regions like Kerala illustrate the potential of place-based eco-centric pedagogy, where the local environment—particularly marine and coastal ecosystems—serves as a valuable learning resource. Educators in Kerala use real-world ecological challenges, such as coastline erosion and marine conservation, to engage students actively in sustainability initiatives. However, the region's unique environmental conditions also impose infrastructural challenges, especially during monsoon seasons, which necessitate more resilient educational facilities.

This study emphasizes that successful eco-centric pedagogy requires a tailored approach that aligns curriculum and instructional practices with the specific socio-environmental context of each region. In addition, robust infrastructural support and community involvement are crucial across all settings to ensure that eco-centric education can be both effective and resilient. Furthermore, the findings highlight the potential of AI to enrich eco-centric education, particularly in urban settings, although its integration must be approached with an awareness of accessibility issues. By addressing these regional nuances and infrastructure needs, policymakers and educators can better support sustainable education that not only meets global sustainability goals but also fosters environmental awareness and responsibility among students. This research suggests the necessity for future studies to explore long-term impacts and further develop frameworks for adapting eco-centric pedagogy to diverse cultural and geographical contexts.

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