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Learners' Awareness and Engagement with Sustainability Education Through AI-Driven Service-Learning: Implications for Educational Practice

Olufiropo Emmanuel Alalade
Department of Social Sciences and Commerce Education, Faculty of Education, University of the Free State, Bloemfontein, SOUTH AFRICA,AlaladeOE@ufs.ac.za

Abstract
This study investigated senior secondary school students' experiences and perceptions of AI-driven service-learning for sustainability education, with a specific focus on their awareness and attitudes toward green materials and sustainable practices. Guided by a descriptive survey research design, the study involved 251 students from four purposively selected secondary schools in the Obollo-Afor Education Zone of Enugu State, Nigeria. These schools were chosen based on their access to ICT facilities, AI-integrated learning platforms, and consistent electricity supply, ensuring a supportive environment for technology-enhanced learning. Data were collected using the Students' Experiences and Perceptions of AI-Driven Service-Learning for Sustainability Education Questionnaire (SEPASLEQ), which was adapted from validated instruments and subjected to expert validation and pilot testing. The instrument exhibited strong internal consistency, with a Cronbach's alpha coefficient of 0.81. Descriptive statistics, including mean and standard deviation, were used to answer the research questions. Findings indicated that students showed a high level of awareness and understanding of sustainability concepts and green materials, held positive attitudes toward sustainable practices, and acknowledged the value of AI-supported service-learning in enhancing their engagement. However, the actual integration of AI tools and structured service-learning experiences in classrooms remained limited. The results highlight the importance of aligning curriculum implementation with technological and experiential innovations to effectively equip learners for sustainable development goals.

Keywords: *Artificial Intelligence, Service-Learning, Sustainability Education, Green Materials, Environmental Awareness, Secondary School Students*

INTRODUCTION

Learners' awareness and understanding of sustainability are critical for preparing environmentally responsible citizens capable of addressing urgent global challenges such as climate change, pollution, biodiversity loss, and unsustainable resource use. As environmental crises become more complex and interconnected, there is growing recognition that education systems must do more than simply deliver content, they must empower students to think critically, act responsibly, and contribute meaningfully to sustainable development (Egara & Mosimege, 2023a; Okeke et al., 2025; Begum et al., 2021; Zhang et al., 2022; Gupta et al., 2024).

Despite the integration of environmental topics into school curricula, many students, especially in developing contexts, demonstrate limited understanding of sustainability and show low levels of active engagement in environmentally responsible practices (Adedara, 2021; Egara & Mosimege, 2023b). This gap is often attributed to conventional teaching approaches that fail to contextualize learning in real-life situations, limiting students' ability to connect theoretical knowledge with practical, local solutions (Okafor et al., 2023a, 2023b; Okeke et al., 2023; Osakwe et al., 2022).

To address these challenges, pedagogical strategies that prioritize experiential and participatory learning have gained prominence. One such approach is service-learning, which links academic content with structured community service and reflective activities. Service-learning not only deepens conceptual understanding but also fosters values such as civic responsibility, collaboration, and social accountability (Alalade, 2023; Samino, 2023). When applied to sustainability education, service-learning can provide students with authentic

opportunities to explore and address environmental issues through projects like recycling drives, community clean-up efforts, and tree-planting initiatives.

Alongside these pedagogical shifts, Artificial Intelligence (AI) is increasingly transforming the educational landscape. AI tools, ranging from personalized tutoring systems to virtual labs and interactive learning platforms, offer new ways to engage students and tailor instruction to individual needs (Mohamed et al., 2022). When integrated with service-learning, AI can enhance students' planning, reflection, and feedback processes, making environmental learning more personalized, dynamic, and impactful. Despite the promising potential of AI-enhanced service-learning, there is limited empirical evidence on how such integrated approaches influence learners' awareness, attitudes, and engagement with sustainability. In particular, little is known about the extent to which students are exposed to these tools and experiences, and how they perceive their impact on their understanding of environmental issues.

Theoretical Framework

This study is grounded in two interrelated theoretical perspectives: Experiential Learning Theory by David Kolb (1984) and Sociocultural Theory by Lev Vygotsky (1978). These frameworks provide a comprehensive foundation for understanding how students develop awareness, attitudes, and knowledge about sustainability through AI-supported service-learning experiences.

Kolb's Experiential Learning Theory posits that meaningful learning occurs through a cyclical process comprising four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. In the context of this study, students engage in service-learning projects that serve as concrete experiences—such as participating in environmental campaigns, recycling initiatives, or other school-based sustainability efforts. Through reflective observation, students consider the significance of their experiences, often supported by digital tools that provide feedback or guide their thinking. Abstract conceptualization follows as students relate these experiences to theoretical knowledge about sustainability. Finally, in the stage of active experimentation, learners apply their insights to new tasks or challenges, reinforcing their learning and fostering deeper environmental understanding.

Complementing this experiential perspective, Vygotsky's Sociocultural Theory emphasizes the social nature of learning. According to Vygotsky, knowledge is constructed through interactions with others and mediated by cultural and technological tools. In this study, the integration of artificial intelligence serves as a key mediating tool that facilitates learning. AI platforms such as intelligent tutoring systems, educational chatbots, or virtual simulations enable students to receive tailored guidance, immediate feedback, and scaffolded support, thereby enhancing their cognitive engagement and comprehension. Additionally, the collaborative nature of service-learning, where students work in teams and engage with teachers or community members, reflects the importance of social interaction and guided participation in constructing meaning.

Together, these two theories offer a robust framework for examining how AI-driven service-learning can influence students' awareness, attitudes, and engagement with sustainability. Kolb's theory emphasizes the role of direct experience and reflection in learning, while Vygotsky's theory highlights the importance of social context and technological mediation. The combination of experiential and sociocultural dimensions provides a nuanced understanding of how learners internalize sustainability concepts through active, socially-situated, and digitally-supported educational practices. These theoretical perspectives therefore align well with the study's objectives, which seek to explore the extent to which students' knowledge, attitudes, and perceptions are shaped by their exposure to AI tools and structured service-learning experiences.

Literature Review

This section reviews empirical studies related to students' exposure to AI technologies, service-learning experiences, and their understanding of sustainability and green innovations, with a focus on green materials and sustainable practices. The application of Artificial Intelligence (AI) in educational settings has expanded significantly, offering new ways to enhance student learning experiences. Holmes et al. (2019) conducted a cross-national survey examining students' perceptions of AI tools in science classrooms, finding that personalized feedback and interactive simulations provided by AI platforms improved students' understanding of complex scientific concepts. Egara et al. (2025) investigated secondary school students'

awareness of AI-based tools such as ChatGPT in mathematics learning. Their findings indicated that students were aware of AI's educational potential and experienced increased motivation and engagement when using these tools. Egara and Mosimege (2024) explored teachers' perspectives on AI integration in mathematics instruction, highlighting both benefits and challenges. Their study emphasized the importance of careful curricular alignment and adequate teacher support for successful AI adoption. Together, these studies suggest that students appreciate AI's potential benefits, but effective implementation depends on structured integration and teacher readiness.

Service-learning is increasingly recognized as an effective method that combines academic content with real-world community engagement to promote civic responsibility and active learning. Within sustainability education, service-learning enables students to apply environmental concepts to address community needs, fostering deeper understanding and positive attitudes toward sustainable practices. Adedara (2021) found that service-learning strategies improved senior secondary students' knowledge of social issues in Nigeria, though changes in attitudes and academic performance were less evident. This study did not examine the role of emerging technologies like AI in service-learning, a gap this study aims to fill by investigating AI-driven service-learning to enhance students' understanding of sustainability concepts and green materials.

International studies support the transformative potential of service-learning in scientific and civic education. Zahedi et al. (2023) reported that service-learning in Indian middle schools increased civic engagement and community awareness, outcomes critical to sustainability education. Komalasari and Saripudin (2019) showed that service-learning embedded in Indonesian social studies curricula enhanced students' social care and environmental consciousness. Filges et al. (2022) reviewed 37 service-learning studies and called for more rigorous research outside the United States in diverse educational contexts. This study responds by examining AI-enhanced service-learning in Nigeria, assessing cognitive and affective outcomes related to students' sustainability knowledge and commitment.

Students' knowledge and attitudes toward sustainability and green materials vary considerably, influenced by school type, curriculum quality, and exposure to environmental education. Olajire (2020) found that junior secondary students in private schools in Southwest Nigeria had higher environmental literacy than those in public schools, attributed to better access to teaching resources and structured programs. Nonetheless, both groups showed limited understanding of specific green materials and sustainable technologies, indicating curricular gaps. Egbezor and Brisk-Elemele (2016) linked exposure to environmental education with increased pro-environmental behaviours among senior secondary students in Port Harcourt, Nigeria. However, they stressed that translating knowledge into sustainable actions requires continuous reinforcement through school and community activities. Similarly, Wandera et al. (2022) found moderate environmental literacy but only moderate engagement in sustainable practices among Ugandan secondary students, recommending curricula enriched with community-based projects. Mahinay et al. (2023) also observed uneven willingness to engage in pro-environmental behaviour among Filipino senior high school students despite awareness of ecological issues, highlighting the need for programs that integrate knowledge with practical actions.

Although AI tools and service-learning independently show promise in enhancing engagement and understanding of sustainability topics (Holmes et al., 2019; Egara et al., 2025; Zahedi et al., 2023; Komalasari & Saripudin, 2019), limited research exists on their combined effect. Specifically, there is a gap in understanding how AI-enhanced service-learning influences students' awareness, attitudes, and engagement with green materials and sustainable practices. This study aims to address this gap by investigating senior secondary students' knowledge and attitudes toward sustainability education in the context of AI-driven service-learning. It seeks to provide practical insights for curriculum development and educational practice, advancing the integration of AI and service-learning as complementary strategies to promote sustainability literacy and positive environmental behaviours.

Research Questions

1. What is the level of students' awareness and understanding of green materials and sustainability concepts?
2. What are students' attitudes toward the use of green materials and sustainable practices?

3. To what extent are students exposed to AI tools and service-learning experiences in their school environment?
4. How do students perceive the impact of AI-driven service-learning on their understanding and engagement with sustainability?

Methods

Research Design

This study adopted a descriptive survey research design to investigate students' awareness, attitudes, and engagement with sustainability education through AI-driven service-learning experiences. The choice of a descriptive survey design is appropriate because it allows the researcher to gather quantifiable information from a large sample and describe the existing conditions without manipulating any variables (Creswell & Creswell, 2018). This method is particularly effective for studies focused on measuring attitudes, perceptions, and self-reported behaviours across diverse themes.

Population, Sample, and Sampling Technique

The population for this study consisted of all Senior Secondary School students (SS1–SS3) within the Obollo-Afor Education Zone of Enugu State, Nigeria. This group was chosen because they are at an educational stage where subjects such as Civic Education, Agricultural Science, ICT/Computer Studies, and Geography incorporate foundational content on environmental education, sustainability, and scientific innovation. These subjects provide students with opportunities to engage with environmental issues and, increasingly, with technological tools like artificial intelligence (AI) in the learning process.

A purposive sampling technique was employed to select schools that met specific inclusion criteria. Four secondary schools were selected based on the following factors: the presence of functional ICT laboratories, reliable electricity supply, and access to AI-integrated educational platforms. These criteria were essential to ensure that participants had realistic exposure to AI-supported learning environments and the potential to participate in structured service-learning initiatives within the school context. From the selected schools, a total of 251 students who met the study's inclusion criteria were sampled to participate. These students had varying degrees of exposure to sustainability-related content and AI tools, making them suitable respondents for investigating awareness, attitudes, experiences, and perceived impacts of AI-driven service-learning in promoting environmental education. This sampling approach ensured that data collection was both contextually relevant and capable of yielding meaningful insights into the intersection of educational technology and sustainability learning among secondary school students in the region.

Instrumentation, Validity and Reliability

The primary data collection instrument for this study was a structured questionnaire titled *Students' Experiences and Perceptions of AI-Driven Service-Learning for Sustainability Education Questionnaire (SEPASLEQ)*. The questionnaire was developed based on a thorough review of relevant literature and existing validated instruments measuring students' environmental knowledge, attitudes, and technology-related experiences. Items were adapted from established tools such as the *Environmental Attitudes Inventory* (Milfont & Duckitt, 2010) and recent educational technology surveys on AI awareness and integration (e.g., Holmes et al., 2019). SEPASLEQ was designed to assess four key constructs: (1) Awareness and Understanding of Green Materials and Sustainability Concepts; (2) Students' Attitudes Toward Green Materials and Sustainable Practices; (3) Exposure to AI Tools and Service-Learning Experiences in School; and (4) Perceived Impact of AI-Driven Service-Learning on Understanding and Engagement. The questionnaire contains 20 items, with five items representing each theme. Respondents rated items on a 4-point Likert scale ranging from Strongly Agree (4) to Strongly Disagree (1), a design choice intended to eliminate neutral responses and encourage more decisive answers (Boone & Boone, 2012).

The instrument underwent face and content validation by three experts specializing in educational technology, environmental education, and measurement and evaluation to ensure the questionnaire's clarity and relevance. To assess reliability, the questionnaire was pilot tested on 45 senior secondary school students

from a school outside the study area but with similar characteristics. The Cronbach's alpha coefficient for the entire scale was 0.81, indicating high internal consistency and reliability of the instrument.

Data Collection Procedure

Data were collected using the validated SEPASLEQ. Ethical approval was obtained from relevant authorities, and informed consent was secured from participants and, where necessary, their parents or guardians. The instrument was administered in four purposively selected secondary schools in the Obollo-Afor Education Zone, each equipped with adequate ICT facilities and access to AI-integrated learning platforms. The research team visited each school at scheduled times and administered the questionnaires during regular class periods. Clear instructions were provided, and participants were assured of confidentiality and the voluntary nature of their participation. On average, each student completed the questionnaire within 5 to 10 minutes. The administration process was carried out in multiple sessions, depending on school size and class organization. A total of 251 students across the four schools participated. The completed responses were reviewed for completeness, coded, and prepared for statistical analysis.

Method of Data Analysis

The data collected were entered and analysed using the Statistical Package for the Social Sciences (SPSS), Version 28. Descriptive statistics, specifically mean (M) and standard deviation (SD), were employed to address the research questions and provide a summary of students' responses across the four thematic constructs of the questionnaire. A standardized decision benchmark was adopted to interpret the responses on the 4-point Likert scale. Mean scores ranging from 1.00 to 1.49 were interpreted as *Strongly Disagree*, 1.50 to 2.49 as *Disagree*, 2.50 to 3.49 as *Agree*, and 3.50 to 4.00 as *Strongly Agree*. This analytical approach enabled a structured and interpretable presentation of students' levels of awareness, attitudes, exposure, and perceived impacts, in line with the descriptive orientation of the study.

Results

This section presents the analysed results based on the four research questions guiding the study.

Research Question 1: What is the level of students' awareness and understanding of green materials and sustainability concepts?

Table 1

Awareness and Understanding of Green Materials and Sustainability Concepts

S/N	Items	*M*	*SD*	Decision
1	I am familiar with the term "green materials."	2.84	1.11	Agree
2	I understand how sustainable practices help protect the environment.	2.65	1.11	Agree
3	I can identify common green materials used in everyday products.	2.31	.89	Disagree
4	I have learned about sustainability topics in school.	2.19	.94	Disagree
5	I can explain the importance of sustainability in society.	2.63	1.13	Agree
	Grand Mean	**2.52**	**1.04**	**Agree**

The grand mean of 2.52 with a standard deviation of 1.04 (see Table 1) indicates that students possess a moderate level of awareness and understanding of green materials and sustainability concepts. They showed familiarity with terms such as *"green materials"* (M = 2.84, SD = 1.11) and expressed understanding of the benefits of sustainable practices (M = 2.65, SD = 1.11) and their importance in society (M = 2.63, SD = 1.13). However, lower scores on identifying specific green materials (M = 2.31, SD = 0.89) and exposure to sustainability education in school (M = 2.19, SD = 0.94) suggest limited practical knowledge and insufficient curricular integration. This highlights the need for more comprehensive and applied sustainability education in the school environment.

Research Question 2: What are students' attitudes toward the use of green materials and sustainable practices?

Table 2

Students' Attitudes Toward Green Materials and Sustainable Practices

S/N	Items	*M*	*SD*	Decision
6	I believe using green materials is essential for a better future.	2.32	1.16	Disagree
7	I am interested in learning more about sustainability and the environment.	2.67	1.01	Agree
8	I support the idea of adopting sustainable practices in my daily life.	2.43	.84	Disagree
9	I feel responsible for helping to protect the environment.	2.64	1.10	Agree
10	I think sustainability should be emphasized more in schools.	2.79	1.14	Agree
	Grand Mean	**2.57**	**1.05**	**Agree**

The grand mean of 2.57 with a standard deviation of 1.05 (see Table 2) suggests that students generally have a positive attitude toward green materials and sustainable practices. While they agreed that sustainability should be emphasized in schools (M = 2.79, SD = 1.14) and showed interest in learning more about environmental issues (M = 2.67, SD = 1.01), there was moderate hesitation about adopting sustainable habits in daily life (M = 2.43, SD = 0.84) and recognizing the importance of green materials (M = 2.32, SD = 1.16). These findings imply that although students value sustainability conceptually, their commitment to personal action may still require reinforcement through targeted environmental education and awareness campaigns.

Research Question 3: To what extent are students exposed to AI tools and service-learning experiences in their school environment?

Table 3

Exposure to AI Tools and Service-Learning Experiences in School

S/N	Items	*M*	*SD*	Decision
11	I have used AI tools (e.g., ChatGPT, educational apps) in my schoolwork.	2.43	.93	Disagree
12	My school encourages the use of AI to support learning.	2.43	.10	Disagree
13	I have participated in service-learning projects in school.	2.40	.90	Disagree
14	My service-learning experiences included topics on sustainability.	2.15	.87	Disagree
15	I have received guidance on using AI tools for academic purposes.	2.28	.88	Disagree
	Grand Mean	**2.34**	**0.74**	**Disagree**

The grand mean of 2.34 with a standard deviation of 0.74 (see Table 3) reveals that students generally reported low exposure to AI tools and service-learning experiences within their school environments. While some students acknowledged using AI tools in their schoolwork (M = 2.43, SD = 0.93), there was limited participation in service-learning initiatives, especially those focused on sustainability (M = 2.15, SD = 0.87). Moreover, guidance on how to use AI academically was insufficient (M = 2.28, SD = 0.88). These results underscore the need for schools to adopt more structured programs that integrate AI tools and service-learning projects, especially those linked to sustainability education, to foster deeper student engagement and practical learning experiences.

Research Question 4: How do students perceive the impact of AI-driven service-learning on their understanding and engagement with sustainability?

Table 4

Perceived Impact of AI-Driven Service-Learning on Understanding and Engagement

S/N	Items	*M*	*SD*	Decision
16	AI tools make learning about sustainability more engaging.	2.51	1.05	Agree
17	AI-supported service-learning projects help me understand sustainability better.	2.29	.97	Disagree

18	I feel more motivated to learn about the environment through AI-based projects.	2.30	.88	Disagree
19	Combining AI with service-learning improves my interest in solving real-world problems.	2.19	.93	Disagree
20	AI-driven service-learning has influenced me to take environmental action.	2.43	1.01	Disagree
	Grand Mean	**2.34**	**0.97**	**Disagree**

The grand mean of 2.34 with a standard deviation of 0.97 (see Table 4) suggests that students do not strongly perceive AI-driven service-learning as significantly improving their understanding or engagement with sustainability concepts. While some respondents found AI tools engaging for learning about sustainability (M = 2.51, SD = 1.05), most did not feel that such tools or projects notably motivated them (M = 2.30, SD = 0.88) or improved their interest in real-world problem-solving (M = 2.19, SD = 0.93). These findings point to the necessity of better-designed, interactive, and contextually relevant AI-based service-learning interventions to enhance student impact and meaningful participation.

Discussion

This study set out to explore senior secondary school students' experiences and perceptions of AI-driven service-learning in promoting sustainability education, with a focus on environmental awareness, green materials, and sustainable practices. Drawing on experiential and sociocultural learning theories, the study assessed students' understanding, attitudes, exposure, and the perceived impact of integrating AI tools within service-learning projects. Descriptive statistics provided insights across four thematic dimensions.

Awareness and Understanding of Green Materials and Sustainability Concepts

The findings revealed a moderate level of awareness and understanding, with a grand mean of 2.52. Items such as students recognizing the benefits of reusing materials and identifying eco-friendly materials were rated slightly above the midpoint, suggesting emerging but incomplete comprehension. This result may be due to fragmented coverage of environmental topics across subjects like Civic Education and Agricultural Science. While these subjects include elements of sustainability, they often lack coherence and depth, particularly regarding green materials and innovation. This finding aligns with Olajire (2020), who found that while students in Nigerian schools had some awareness of environmental issues, knowledge about specific green innovations was lacking. Similarly, Mahinay et al. (2023) reported uneven comprehension of ecological concepts among Filipino students. From Kolb's Experiential Learning Theory, students may have lacked the "concrete experience" stage, where practical engagement with green materials (e.g., school recycling initiatives or eco-projects) would anchor abstract concepts. According to Vygotsky's Sociocultural Theory, without sufficient mediated tools (e.g., simulations or collaborative tasks), students may not have internalized sustainability knowledge effectively.

Students' Attitudes Toward Green Materials and Sustainable Practices

With a grand mean of 2.57, results suggested that most students agreed with pro-sustainability statements. They supported sustainable practices and expressed interest in learning more, although some showed hesitance in expressing strong personal responsibility or daily commitment to environmental protection. Students' generally positive attitudes may stem from increasing global discourse on climate change and environmental degradation, influencing young people through media, school campaigns, and digital content. However, the gap between attitude and behavioural intent may reflect limited practical engagement opportunities. These findings resonate with Egbezor and Brisk-Elemele (2016) and Wandera et al. (2022), who found favourable attitudes among African students toward sustainability, though translating these attitudes into sustained behaviour remained a challenge. The emphasis on school-community collaboration in Komalasari and Saripudin (2019) also underscores the need to bridge attitude and action. This dimension reflects Vygotsky's principle that values and dispositions are culturally mediated. Without social interaction and role models demonstrating sustainable living, students may not fully embrace responsibility. Similarly,

Kolb's model would suggest that students need more opportunities to engage in active experimentation, like school gardens or cleanup drives, to transform positive attitudes into action.

Exposure to AI Tools and Service-Learning Experiences in School

The grand mean of 2.34 showed that students had limited exposure to AI tools and service-learning experiences. While some students reported using AI tools like ChatGPT or educational apps, many lacked structured school support or curriculum alignment in this area. Furthermore, service-learning projects related to sustainability were inconsistently reported. Despite access to ICT infrastructure in the selected schools, integration of AI into the curriculum appears minimal. Teachers may not be adequately trained to incorporate AI, and service-learning may not be institutionalized in most Nigerian secondary schools. These findings support Egara et al. (2025) and Egara and Mosimege (2024), who stressed that although awareness of AI tools among students is growing, structured implementation in African classrooms remains inconsistent. Similarly, Adedara (2021) highlighted the potential of service-learning but noted its underutilization in Nigeria's secondary education system. From Vygotsky's lens, the lack of scaffolding tools and social support limits learning potential. AI tools serve as mediating artifacts that, when absent or unstructured, hinder development. Kolb's theory further suggests that without "concrete experience" and "active experimentation," students cannot meaningfully apply technological tools to real-world learning scenarios.

Perceived Impact of AI-Driven Service-Learning on Understanding and Engagement

This construct yielded the lowest grand mean of 2.34, indicating that students perceived limited impact of AI-enhanced service-learning on their understanding and motivation toward sustainability. Given the previously noted limited exposure to AI and service-learning, it follows logically that students would struggle to recognize their impact. The novelty of AI tools in classroom environments, combined with a lack of service-learning policy support, may account for the weak perceived benefits. This is in contrast with Holmes et al. (2019), who observed increased engagement and conceptual clarity when AI was effectively deployed in science classrooms. It also contrasts with Zahedi et al. (2023), who demonstrated the efficacy of service-learning in building civic and environmental engagement. These discrepancies highlight implementation gaps in the Nigerian context. Kolb's learning cycle was likely disrupted for these students. Without structured AI-supported learning projects, students missed key phases of reflection and experimentation. Vygotsky's Sociocultural Theory similarly underscores that learning is socially constructed and mediated by tools, underscoring the need for guided, interactive AI applications to achieve deep learning outcomes.

Conclusion

This study revealed that while senior secondary students exhibited moderately positive attitudes toward green materials and sustainable practices, their actual exposure to AI tools and structured service-learning experiences remains insufficient. The relatively low perceived impact of AI-driven service-learning on their understanding and engagement highlights the gap between curricular potential and practical implementation. Despite the presence of ICT infrastructure in selected schools, students reported limited use of AI for academic or sustainability-related purposes, and few had participated in service-learning activities explicitly tied to environmental themes. These patterns suggest that while there is foundational awareness and openness among students, more structured and consistent integration of AI-supported, experiential learning opportunities is necessary to fully realize their educational benefits. Overall, the results point to the importance of bridging technological availability with meaningful pedagogy. Without intentional design and guidance, the promise of AI-enhanced service-learning may remain untapped in fostering environmental awareness and action among learners.

Limitations and Suggestions for Future Studies

While this study provides valuable insights into students' experiences and perceptions of AI-driven service-learning for sustainability education, several limitations should be acknowledged. Firstly, the study was confined to four purposively selected secondary schools within the Obollo-Afor Education Zone of Enugu State, Nigeria. This limited geographical scope may constrain the generalizability of the findings to other regions with different levels of technological infrastructure, curricular emphasis, or socio-cultural dynamics. Secondly, the study relied exclusively on quantitative self-report data gathered through structured

questionnaires. Although this approach allowed for the efficient collection of data from a relatively large sample, it may have introduced biases such as socially desirable responses or misunderstandings of certain items. The absence of complementary qualitative data (e.g., interviews, focus groups, or classroom observations) limits the depth of understanding regarding students' lived experiences and contextual interpretations of AI and service-learning.

To address these limitations, future research should consider expanding the study to include a more diverse and representative sample from different educational zones and states. Incorporating a mixed-methods approach, including interviews and observations, would offer richer insights into how AI tools and service-learning practices are experienced in real-world settings. Additionally, future studies could examine the perspectives of teachers and school administrators to gain a more holistic view of implementation challenges and opportunities.

Educational Implications and Recommendations

The findings of this study underscore several important educational implications for enhancing sustainability education through AI-driven service-learning. First, it is evident that while AI tools are increasingly available in schools, their integration into pedagogical practices requires purposeful and strategic efforts. Rather than merely providing access to technology, schools need to embed AI meaningfully within the curriculum to serve as active facilitators of learning. When used effectively, AI can provide personalized feedback and scaffold students' understanding of complex sustainability concepts, thereby enriching the learning experience.

Moreover, service-learning projects remain a vital but underutilized avenue for connecting academic content with real-world environmental issues. Expanding and structuring these opportunities, particularly by incorporating AI tools, can enhance experiential learning and motivate students to adopt more sustainable behaviours. However, the successful implementation of AI-enhanced service-learning hinges largely on teacher readiness. Continuous professional development is crucial to equip educators with the necessary skills to integrate AI technologies effectively and to design impactful service-learning experiences that align with sustainability objectives.

Curriculum enhancement is also necessary to bridge the gap between theory and practice in environmental education. By embedding clear frameworks for AI-supported activities and service-learning projects, curricula can ensure that sustainability education moves beyond abstract concepts to involve meaningful community engagement.

Based on these implications, several recommendations are proposed. Educational authorities and schools should prioritize the development and implementation of AI-enhanced service-learning modules that blend technology with hands-on sustainability projects. Such initiatives will require collaboration among schools, technology providers, and environmental experts to create relevant and effective learning experiences.

Teacher training programs must be expanded to include comprehensive instruction on the use of AI in the classroom, pedagogical strategies for service-learning, and assessment methods to evaluate sustainability learning outcomes. Enhancing teacher capacity will enable more effective facilitation of AI-driven sustainability education.

In addition, efforts should be made to increase student engagement with AI tools, not only through infrastructure investment but also by promoting active, meaningful use of these technologies in learning activities. Schools can leverage interactive simulations, virtual laboratories, and AI-powered environmental data tools to make sustainability education more dynamic and accessible.

Further, forging strong partnerships between schools and community organizations is essential to provide authentic service-learning opportunities. These partnerships will allow students to apply their knowledge and technological skills to address real-world environmental challenges, fostering a deeper sense of civic responsibility.

Finally, it is vital to establish ongoing monitoring and evaluation mechanisms to assess the effectiveness of AI-driven service-learning programs. Continuous feedback and refinement will ensure these educational innovations achieve their intended outcomes and remain responsive to student needs.

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