Multidisciplinary Reviews

QUESTIONNAIRES APPLICATION
Published Online: June 2, 2025
https://doi.org/10.31893/multirev.2025429

AI-driven service-learning to enhance students' understanding of green nanomaterials in sustainability education

Chinonso Anthony Ofozoba[a] | Patrick Chinenye Okafor[b] | Njideka Gloria Ikegbusi[b] | Fausta Uche Manafa[c] | Joyce Uche Egwu[b] | Chukwudi Michael Nwobu[a] | Scholarstica Ogechukwu Okafor[b] | Mary Adesola Onafowope[d] | Vincent Kayode Olofinkua[d] | Joseph Olusegun Adeagbo[e] | Oweikpodor Vera Gbaeprekumo[f] | Victor Olugbenga Ayoko[c] | Anthony Nnaemeka Udogu[g] | Ngozi Caroline Uwannah[h] | Odinakolisa Christopher Okudo[b] | Blessing Onyeka Onyiorah[i] ✉ | Mesu Felicia Ayodele[j] | Ogochukwu Gloria Nnonyelu[k] | Juliet Chika Ekwugha[l] | Amaka Ekwesianya[i] | Obioma Henrietta Nnalue[m]

[a]Department of Arts and Social Science Education, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.
[b]Department of Educational Foundations, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.
[c]Department of Educational Foundations, National Open University of Nigeria, Abuja, Nigeria.
[d]Department of Educational Management, St. Augustine College of Education, Akoka, Lagos State, Nigeria.
[e]Department of Educational Management, Emmanuel Alayande University of Education, Oyo State, Nigeria.
[f]Department of Educational Management and Foundations, Delta State University, Abraka, Nigeria.
[g]Department of Criminology and Security Studies, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.
[h]Department of Education, Babcock University, Ogun State, Nigeria.
[i]Department of Vocational Education, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.
[j]Our Lady of Apostles Secondary School, Yaba, Lagos State, Nigeria.
[k]Department of Business Education, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.
[l]Department of Economics, Kingsley Ozumba Mbadiwe University, Imo State, Nigeria.
[m]Department of Science Education, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

Abstract This study investigated senior secondary school students' understanding of and attitudes toward nanotechnology-enhanced green materials and sustainability, with a focus on their exposure to artificial intelligence (AI)-driven service-learning experiences. Anchored in a descriptive survey research design, the study targeted 232 students from three purposefully selected ICT-equipped schools in the Nsukka Education Zone of Enugu State, Nigeria. These schools were chosen for their access to AI-based learning platforms and the integration of environmental education topics across relevant subjects. Data were collected via the *Students' Knowledge and Attitudes toward Nanotechnology-Enhanced Green Materials and Sustainability Questionnaire (SKANSQ)*, which was developed through a literature review and expert validation. The instrument demonstrated high reliability, with a Cronbach's alpha coefficient of 0.83. The questionnaire measured students' knowledge, attitudes, exposure to AI tools and service-learning activities, and perceptions of how these experiences influenced their understanding of sustainability concepts. Descriptive statistics, means and standard deviations, were employed to address the research questions. The findings revealed that while students reported a moderate level of knowledge and demonstrated generally positive attitudes toward sustainability and green innovations, their actual exposure to AI-supported learning and community-based service-learning projects was relatively low. The results suggest a gap between curricular intentions and the practical implementation of experiential and technology-enhanced learning strategies. This study underscores the need for schools and policymakers to promote more deliberate integration of AI tools and service learning into science and environmental education to better prepare students for global sustainability challenges.

Keywords: AI, attitude, environment, nanotechnology, service-learning

1. Introduction

Education is widely acknowledged as a powerful instrument for personal development, societal advancement, and sustainable global progress (Egara & Mosimege, 2023b; Okeke et al., 2025). Through structured curricula and innovative pedagogies, education equips learners with the knowledge, skills, and values necessary to address complex challenges such as climate change, resource depletion, and environmental degradation (Begum et al., 2021; Kizildeniz & Bozkurt, 2024; Zhang et al., 2022). However, in many regions, particularly within developing countries, students' performance in science- and environment-related subjects has remained below expectations (Adedara, 2021; Egara & Mosimege, 2023a; Mosia et al., 2025).

This learning gap is often attributed to conventional teaching methods that fail to actively engage learners or contextualise content to real-world problems (Okeke et al., 2023; Osakwe et al., 2022).

A key subject area affected by this disconnect is environmental education (Gupta et al., 2024). To foster ecological literacy, sustainable practices, and environmental stewardship, environmental education is central to achieving the United Nations' Sustainable Development Goals (SDGs). Over the years, there has been growing advocacy for pedagogical innovations that make environmental learning more meaningful and action oriented (United Nations Educational, Scientific and Cultural Organisation [UNESCO], 2019). Among these, service learning has emerged as an effective approach that integrates community service with structured learning and reflective practice (Alalade, 2023). This method empowers students to engage in authentic projects, such as local clean-up campaigns, recycling initiatives, or tree planting, that directly apply their classroom knowledge to real-life sustainability challenges (García, 2023).

With the advent of digital technologies, artificial intelligence (AI) has begun to shape educational experiences in novel ways. AI applications in education can provide personalised content, real-time feedback, and intelligent tutoring systems that adapt to student needs, thereby increasing learner engagement and comprehension (Mohamed et al., 2022). When integrated into service learning, AI can support students in planning, monitoring, and reflecting on their community-based environmental projects—making the learning experience more responsive and impactful.

Simultaneously, the rise of nanotechnology offers new frontiers in environmental sustainability. Nanotechnology-enhanced green materials, such as biodegradable packaging, nanoscale water purification systems, and nanosolar energy devices, are revolutionising eco-friendly practices (Roco & Bainbridge, 2013). These scientific advancements provide rich, relevant content for environmental education, yet many students are unaware of their existence or significance.

Despite these converging trends in pedagogy and technology, there is limited empirical evidence on how AI-driven service-learning influences students' understanding of and attitudes toward these emerging green innovations. This raises important questions: do students possess adequate knowledge of nanotechnology-based green materials? What are their attitudes toward sustainability and the application of advanced technologies in solving environmental problems? How can educators design learning environments that foster both knowledge and commitment to sustainable practices? These questions are particularly urgent in the context of preparing the next generation of environmentally conscious citizens. Thus, the current study seeks to examine students' knowledge and attitudes toward nanotechnology-enhanced green materials and sustainability within an educational framework that incorporates AI-supported service learning.

This study is anchored in two interrelated educational theories: experiential learning theory (Kolb, 1984) and constructivist learning theory (Vygotsky, 1978). These theories provide a solid conceptual foundation for understanding how students develop knowledge, perceptions, and attitudes through technology-integrated, sustainability-oriented, and community-based learning contexts. *Kolb's Experiential Learning Theory* posits that learning occurs through a cyclical process of concrete experience, reflective observation, abstract conceptualisation, and active experimentation. In the context of this study, students may engage with sustainability and green innovation concepts through service-learning projects, discussions, or exposure to AI-driven tools, even in indirect ways. These experiences, although not always hands-on, can still contribute to meaningful learning through observation and reflection, supporting the development of environmental awareness and values. *Vygotsky's constructivist learning theory* emphasises that learning is socially constructed and mediated by tools, language, and interactions with more knowledgeable others. Within this framework, AI tools and service-learning content function as cognitive scaffolds that help students make sense of complex topics such as green nanotechnology and sustainability. Even without direct instruction, social dialogue, the cultural context, and digital media exposure influence how students internalise and interpret these ideas. Together, these theories frame how students acquire and shape knowledge and attitudes toward environmental innovations in real-world and classroom contexts. They support the study's aim to investigate students' existing awareness, perceptions, and learning conditions that shape them.

This section reviews empirical studies on students' exposure to AI technologies, service-learning experiences, and their understanding of sustainability, particularly nanotechnology-enhanced green materials. AI applications in education have expanded significantly. Holmes et al. (2019) reported that students valued AI tools for personalised feedback and interactive simulations, improving their grasp of complex scientific concepts. Egara et al. (2025) reported that students recognised the potential of AI tools such as ChatGPT in mathematics learning, with many noting increased motivation and conceptual understanding. Egara and Mosimege (2024) examined teachers' perspectives on AI integration, highlighting its instructional benefits and the need for proper curricular alignment and teacher support. These studies suggest that students are generally positive about AI, although effective implementation requires structural and pedagogical support.

Service learning has also emerged as a promising strategy for connecting academic content with real-world challenges. Adedara (2021) reported that service-learning improved students' knowledge of social issues in Nigeria, although it had a limited impact on attitudes or performance and did not explore the role of AI. By integrating AI into service learning, the current study addresses this gap and explores how such an approach can support a deeper understanding of scientific topics such as nanotechnology-based green materials and foster sustainable attitudes. Zahedi et al. (2023) showed that service-learning in Indian middle schools enhances civic engagement and sustainability awareness internationally. Komalasari and Saripudin (2019) reported similar outcomes in Indonesian curricula, emphasising social care and environmental awareness. Filges et al.

(2022), in a review of 37 studies, advocated for more rigorous service-learning research in diverse contexts. This study investigates AI-enhanced service learning in Nigeria and its impact on both cognitive and affective student outcomes.

Studies on environmental literacy show that disparities are influenced by school type and curriculum. Olajire (2020) reported that private school students in Southwest Nigeria had greater environmental literacy than did those in public schools, although both groups lacked an understanding of advanced green technologies. Egbezor and Brisk-Elemele (2016) reported that environmental education was correlated with pro-environmental behaviours in Port Harcourt but emphasised the need for sustained reinforcement. Wandera et al. (2022) reported moderate levels of sustainability practices among Ugandan students and recommended community-based curriculum integration. Similarly, Mahinay et al. (2023) reported that while Filipino students were aware of pollution, their willingness to act sustainably was inconsistent, underscoring the need for action-oriented education.

Despite the promise of AI and service learning individually, few studies have explored their combined effects on students' understanding of advanced green technologies such as nanomaterials. While AI supports science learning (Holmes et al., 2019; Egara et al., 2025) and service-learning fosters environmental value (Zahedi et al., 2023; Komalasari & Saripudin, 2019), studies have not examined how AI-enhanced service-learning can improve both knowledge and attitudes toward sustainability among senior secondary students. This study addresses this gap, offering insights for curriculum development focused on nanotechnology and sustainable education. The primary objective of this study is to investigate the extent to which students in senior secondary schools understand and feel about key issues related to sustainability and green innovations, particularly nanotechnology-enhanced materials. The study seeks to assess students' knowledge and attitudes within an educational environment that incorporates artificial intelligence (AI)-driven service learning.

2. Methodology

The research aims to answer the following questions:

1. What is the average level of students' knowledge about nanotechnology-enhanced green materials and sustainability?
2. What is the average attitude of students toward the use of green materials and sustainable practices?
3. What is the average level of students' exposure to AI tools used in learning and school-based service-learning projects?
4. What are students' general perceptions of how AI-driven service learning influences their understanding of sustainability and green innovation?

2.1. Research design

This study adopted a descriptive survey research design to explore senior secondary school students' knowledge and attitudes toward nanotechnology-enhanced green materials and sustainability within the context of AI-driven service learning. A descriptive survey design is suitable for collecting quantitative data on participants' perceptions, experiences, and attitudes in a natural setting without manipulating the study variables (Creswell & Creswell, 2018).

2.2. Population and sample

The target population comprised all senior secondary school students (SS1–SS3) in the Nsukka Education Zone of Enugu State, Nigeria. The focus was on students who were exposed to environmental education-related topics through subjects such as civic education, biology, chemistry, agricultural science, home economics, ICT/computer studies and geography, where environmental awareness, sustainability, and scientific innovations are typically integrated into the curriculum. Using purposive sampling, three secondary schools with adequate ICT facilities, access to AI-integrated learning platforms, and a reliable electricity supply were selected. These criteria were essential to ensure that the participants had the potential to be exposed to AI-driven learning experiences and school-based service-learning projects. A total of 232 students from these schools participated in the study.

2.3. Instrumentation

This study's primary data collection instrument was a structured questionnaire titled *Students' Knowledge and Attitudes toward Nanotechnology-Enhanced Green Materials and Sustainability Questionnaire (SKANSQ)*. The questionnaire was developed on the basis of a thorough review of the relevant literature and existing instruments that measure students' environmental knowledge, attitudes, and technology-related experiences. The items were adapted from validated instruments such as the Environmental Attitudes Inventory (EAI) by Milfont and Duckitt (2010), the Nanotechnology Awareness Scale used in science education studies (e.g., Shepardson et al., 2011), and AI awareness and integration items from more recent educational technology surveys (e.g., Holmes et al., 2019). The SKANSQ was designed to measure four key constructs: students' knowledge of nanotechnology-enhanced green materials and sustainability, their attitudes toward sustainable practices and green innovations, their exposure to AI tools and school-based service-learning experiences, and their perceptions of the impact of AI-driven service-learning on their understanding of sustainability.

Each item on the questionnaire was rated via a 4-point Likert scale with the following response options: *strongly agree (4)*, *agree (3)*, *disagree (2)*, and *strongly disagree (1)*. The choice of a 4-point scale was intended to eliminate neutral responses and encourage more decisive opinions (Boone & Boone, 2012). The items were phrased clearly and included real-world examples such as biodegradable plastics, solar-powered school tools, recycling campaigns, and AI-based learning platforms (e.g., educational chatbots or smart classroom tools) to ensure accessibility and contextual relevance for senior secondary school students.

2.4. Validity and reliability

The instrument was subjected to face and content validation by three experts in educational technology, environmental education, and measurement and evaluation. To ensure internal consistency, the instrument was pilot tested on 30 students in a secondary school outside the study area with similar characteristics. The Cronbach's alpha coefficient obtained for the entire scale was 0.83, indicating high reliability.

2.5. Data collection procedure

Before data collection, approval was obtained from the school authorities, and informed consent was secured from the participants and their guardians. Three research assistants with backgrounds in education were trained on how to administer the questionnaires ethically and uniformly across all three schools. They were also briefed on how to clarify questionnaire items to respondents without influencing their responses. The researchers and assistants ensured that all 232 questionnaires distributed were duly completed and returned, resulting in a 100% retrieval rate.

2.6. Method of data analysis

The data collected were entered and analysed via the Statistical Package for the Social Sciences (SPSS), Version 28. Descriptive statistics, specifically the mean (M) and standard deviation (SD), were used to answer the research questions. A cut-off point of 2.50 was established as the decision benchmark: mean scores ≥ 2.50 were interpreted as high or positive (indicating sufficient knowledge, favourable attitudes, adequate exposure, or strong perception), and mean scores < 2.50 were interpreted as low or negative. This analytical method allowed for a clear and interpretable summary of the students' responses, which was consistent with the descriptive nature of the study.

3. Results

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

3.1. Students' knowledge of nanotechnology-enhanced green materials and sustainability

Table 1 presents the average level of students' knowledge about nanotechnology-enhanced green materials and sustainability on the basis of their responses to the five items.

Table 1 Knowledge of nanotechnology-enhanced green materials and sustainability.

S/N	Items	M	SD	Decision
1	I understand what nanotechnology means.	2.88	1.10	High
2	I have heard about green materials such as biodegradable plastics and eco-friendly paints.	2.65	1.12	High
3	I can explain how nanotechnology is used in creating environmentally friendly materials.	2.31	0.90	Low
4	I know how green materials help reduce pollution.	2.20	0.94	Low
5	I have learned about renewable energy sources like solar panels and their role in sustainability.	2.65	1.13	High
	Grand Mean	2.54		High

The grand mean of 2.54 (see Table 1) indicates that students generally possess a high level of knowledge about nanotechnology-enhanced green materials and sustainability. They demonstrated awareness of fundamental concepts such as nanotechnology (*M* = 2.88, SD = 1.10), green materials (*M* = 2.65, SD = 1.12), and renewable energy (*M* = 2.65, SD = 1.13). However, the lower scores for application-related items, such as explaining the role of nanotechnology in environmental protection (*M* = 2.31, SD = 0.90) and understanding the pollution-reduction potential of green materials (*M* = 2.20, SD = 0.94), suggest a gap in deeper conceptual understanding and practical knowledge.

3.2. Students' attitudes towards the use of green materials and sustainable practices

Table 2 presents students' attitudes toward the use of green materials and sustainable practices on the basis of their responses to five related items.

Table 2 Attitudes toward green materials and sustainability.

S/N	Items	M	SD	Decision
6	I believe using green materials is important for protecting the environment.	2.34	1.16	Low
7	I prefer using products that are environmentally friendly.	2.68	1.02	High
8	I support using biodegradable materials in my school and home.	2.44	0.83	Low
9	I am willing to take part in school projects that promote sustainability.	2.67	1.10	High
10	Learning about sustainability makes me care more about the environment.	2.75	1.14	High
	Grand Mean	2.58		High

The grand mean of 2.58 (see Table 2) reflects a moderately positive attitude toward using green materials and sustainable practices. The students expressed a strong belief in the importance of environmentally friendly products (M = 2.68, SD = 1.02), a willingness to engage in school projects promoting sustainability (*M* = 2.67, SD = 1.10), and an interest in learning about sustainability (*M* = 2.75, SD = 1.14). However, some ambivalence was noted in their general belief in the importance of green materials (*M* = 2.34, SD = 1.16) and in their support for biodegradables at home and school (*M* = 2.44, SD = 0.83), indicating the need for more targeted awareness campaigns and engagement activities.

3.3. Students' exposure to ai tools and school-based service-learning projects

Table 3 presents the average level of students' exposure to artificial intelligence (AI) tools and their participation in school-based service-learning activities.

Table 3 Exposure to AI and service-learning experiences.

S/N	Items	M	SD	Decision
11	I have used AI tools (e.g., ChatGPT, virtual labs, smart learning apps) in school activities.	2.44	0.94	Low
12	My school projects include real-life community service (e.g., cleaning, awareness campaigns).	2.43	1.03	Low
13	I have worked on assignments that involve using technology to solve environmental problems.	2.40	0.90	Low
14	My teachers include community service activities in the lessons.	2.17	0.87	Low
15	AI tools have helped me understand science and environmental topics better.	2.26	0.88	Low
	Grand Mean	2.34		Low

The grand mean of 2.34 (see Table 3) suggests relatively low to moderate exposure to AI tools and service-learning experiences among the students. While some students reported using AI tools such as ChatGPT or virtual labs (*M* = 2.44, SD = 0.94) and participating in community-based school projects (*M* = 2.43, SD = 1.03), other responses indicated limited involvement in AI-supported assignments for environmental problem-solving (*M* = 2.40, SD = 0.90), teacher-led service-learning integration (*M* = 2.17, SD = 0.87), and learning enhancement through AI tools (*M* = 2.26, SD = 0.88). These results indicate the uneven availability and implementation of AI-driven educational initiatives across schools.

3.4. Students' perceptions of the influence of AI-driven service learning on sustainability understanding

Table 4 presents students' general perceptions of how AI-driven service learning influences their understanding of sustainability and green innovation.

Table 4 Perceptions of AI-driven service-learning influence on sustainability understanding.

S/N	Items	M	SD	Decision
16	AI-powered tools help make service-learning projects more engaging and interesting.	2.53	1.05	High
17	Service-learning projects using AI tools help me connect classroom learning to real-life issues.	2.28	0.97	Low
18	I understand sustainability better because of my participation in AI-supported community projects.	2.30	0.89	Low
19	Working on real-life environmental projects has improved my thinking about future innovation.	2.19	0.93	Low
20	I believe combining technology and service-learning is an effective way to teach environmental education.	2.42	1.01	Low
	Grand Mean	2.34		Low

The grand mean of 2.34 (see Table 4) reveals a generally modest perception of the influence of AI-driven service-learning on students' understanding of sustainability and green innovation. The students agreed that AI tools make service-learning projects more engaging (*M* = 2.53, SD = 1.05) and connect classroom learning to real-life issues (*M* = 2.28, SD = 0.97). However, perceptions were lower regarding improved understanding of sustainability (M = 2.30, SD = 0.89), enhanced thinking about innovation (*M* = 2.19, SD = 0.93), and the overall effectiveness of combining AI and service learning (*M* = 2.42, SD = 1.01). These findings suggest that while students may be open to technology-enhanced service-learning, the integration has not yet significantly deepened their learning experiences.

4. Discussion

This study explored students' knowledge, attitudes, exposure to AI tools, and perceptions regarding the use of AI-driven service-learning for sustainability and green innovation. The findings were discussed in relation to the four themes that emanated from the research questions:

4.1. Knowledge of nanotechnology-enhanced green materials and sustainability

The findings indicate that students generally possess a foundational understanding of nanotechnology-enhanced green materials and sustainability. This suggests prior exposure to core environmental concepts, likely through science curricula, awareness campaigns, or public discourse on climate change. However, their understanding remains superficial and uneven. While students are familiar with concepts such as renewable energy and biodegradable products, their grasp of the role of nanotechnology in advancing sustainable solutions is limited. This gap likely reflects curricular and instructional shortcomings, where basic environmental education is covered, but the application of emerging technologies such as nanotechnology is not sufficiently integrated. These findings align with those of Olajire (2020), who reported general environmental awareness in Nigerian students but limited knowledge of green materials. Wandera et al. (2022) and Mahinay et al. (2023) highlighted similar patterns of basic environmental literacy, with a lack of engagement in complex sustainable practices due to inadequate curriculum design.

These results can be framed via Kolb's experiential learning theory, which emphasises the importance of concrete experience, reflective observation, and active experimentation in deepening learning. While students may understand basic concepts (remembering and understanding), they have not yet moved through the full cycle of experiential learning, which encourages higher-order thinking skills such as application, analysis, and evaluation. To bridge this gap, a pedagogical shift toward inquiry-based and interdisciplinary learning approaches is necessary, allowing students to engage in hands-on problem-solving and experimentation in the context of nanotechnology and sustainability.

4.2. Attitudes towards green materials and sustainability

The findings show that students generally hold positive attitudes toward green materials and sustainable practices. While a few items recorded lower mean scores, the overall results suggest increasing environmental awareness and openness to adopting eco-friendly behaviours. This attitude may be shaped by exposure to environmental messages through curricula, school initiatives, and digital media. Such influences often highlight the impact of climate change and the benefits of sustainability, encouraging students to value green practices.

These findings are consistent with those of Egbezor and Brisk-Elemele (2016), who reported that environmental education fosters pro-environmental behaviours, and Olajire (2020), who reported disparities in environmental engagement due to institutional differences. Komalasari and Saripudin (2019) further showed that service learning improves environmental awareness through practical engagement. Kolb's Experiential Learning Theory helps explain these results. It proposes that learners form knowledge and attitudes through experience, reflection, and application cycles. Even without direct involvement in sustainability projects, students develop positive attitudes through classroom exposure, discussions, and observed practices.

4.3. Exposure to AI and service-learning experiences

The results indicate that students report low levels of exposure to AI tools and school-based service-learning experiences. This suggests that AI integration and structured community service activities remain underdeveloped in the participating schools. The limited exposure may be attributed to infrastructural and policy gaps. Many schools, particularly in developing regions, lack access to the necessary digital technologies and internet connectivity for the regular use of AI tools such as ChatGPT or virtual laboratories. Additionally, service learning is often not formally integrated into curricula, and teachers may not receive adequate training or support for its effective implementation.

These findings align with those of Egara et al. (2025), who noted that while students were aware of AI tools such as ChatGPT, classroom integration remained limited. Similarly, Egara and Mosimege (2024) reported that AI's potential in mathematics instruction was underutilised due to infrastructure issues, a lack of training, and curriculum misalignment. The limited service-learning opportunities also correspond with those of Adedara (2021), who reported that although service-learning improved students' awareness of social issues, its impact on attitudes and academic performance was minimal due to inconsistent implementation. Zahedi et al. (2023) noted that the success of service learning in Indian schools was contingent on its alignment with community needs and student engagement.

Kolb's Experiential Learning Theory helps explain these results, emphasising that learning occurs through cycles of concrete experience, reflective observation, and active experimentation. The limited use of AI tools and the absence of service-learning restrict students' engagement with these cycles, especially the stages of experimentation and reflection. Vygotsky's sociocultural theory further suggests that learning is shaped by the tools available and the social interactions that mediate it. The lack of such tools and guided activities likely explains the shallow engagement with sustainability topics.

4.4. Perceptions of AI-driven service-learning influence on sustainability understanding

The analysis revealed that students generally had low perceptions of the influence of AI-driven service learning on their understanding of sustainability and green innovation. This suggests insufficient exposure to AI-enhanced service-learning experiences or a lack of clarity about their educational value. While some students acknowledged the engagement AI tools brought to projects, this did not consistently translate into deeper learning or critical thinking. This outcome may be attributed to several factors. First, the limited integration of AI tools in underresourced schools means that students rarely interact with these technologies in educational contexts. Second, the disconnect between classroom instruction and real-world sustainability applications may prevent students from seeing the relevance of AI in addressing environmental challenges.

Egara et al. (2025) reported that while students appreciated AI tools for concept clarification, the educational impact was often superficial without structured implementation. Similarly, Egara and Mosimege (2024) stressed the importance of teacher readiness and curriculum alignment for the effective use of AI. Adedara (2021) also reported that service learning had a minimal effect on students' attitudes and academic achievements when it was not linked to clear educational goals or community impact.

Kolb's Experiential Learning Theory offers insight into these findings, indicating that the absence of structured AI-driven service-learning activities prevents students from fully engaging in all stages of the learning cycle, particularly active experimentation and reflective practice. Without these experiences, students struggle to develop a deep understanding of sustainability concepts. Vygotsky's sociocultural theory further suggests that the availability of appropriate tools and social interaction enhances learning. In this case, the lack of AI platforms and collaborative projects may hinder the development of deeper insights into complex environmental issues.

5. Conclusion

The study explored students' knowledge of nanotechnology-enhanced green materials, their attitudes toward sustainability, their exposure to AI tools and service-learning, and their perceptions of AI-driven service-learning's influence on environmental understanding. The findings revealed that students generally have a fair level of knowledge and a positive attitude toward sustainability, suggesting an awareness of the relevance of green innovation. However, the low levels of exposure to AI tools and participation in structured service-learning activities indicate limited practical engagement with these innovative approaches. Moreover, the students did not perceive AI-driven service learning as significantly enhancing their understanding of sustainability, possibly because of insufficient implementation of such practices in their schools. This suggests a critical need for educational institutions to teach sustainability concepts and actively incorporate AI tools and community-based projects into classroom practices.

5.1. Educational implications

This study's findings have several important implications for educational practices, particularly in sustainability education, AI integration, and service-learning. First, the relatively high levels of student knowledge about nanotechnology and green materials suggest that there is a strong foundation on which to build a deeper understanding. Educators should capitalise on this by incorporating more comprehensive discussions on sustainability into the curriculum, focusing on the practical applications of green materials and renewable energy. Teachers can enhance students' understanding and foster a stronger sense of environmental responsibility by providing real-world examples and engaging in hands-on activities.

Additionally, while students showed positive attitudes toward sustainability, particularly with respect to biodegradable materials and renewable energy, there remains an opportunity to strengthen these attitudes further. Educators should prioritise project-based learning that involves students in sustainability-related tasks, such as waste management or environmental advocacy. These types of projects solidify students' attitudes and give them a sense of agency, making them more likely to take ownership of sustainability issues.

The study also highlighted that students' exposure to AI tools was somewhat limited. This suggests a need for schools to expand the use of AI-powered learning platforms, such as virtual labs or AI-assisted projects, to make learning more engaging and interactive. Proper training for both students and educators is essential to ensure the effective use of these tools. Integrating AI into service-learning projects could also increase their relevance and impact, allowing students to connect their classroom learning with real-world environmental challenges.

Furthermore, the study revealed a gap in students' exposure to service-learning projects, which are valuable in linking theoretical learning with practical experience. Schools should make concerted efforts to integrate more service-learning opportunities into the curriculum, especially those centred around environmental issues. These projects help students develop greater awareness of sustainability and foster critical thinking, problem-solving skills, and a sense of civic responsibility.

Finally, to support these changes, professional development is crucial. Teachers need access to the tools, training, and ongoing support necessary to incorporate AI tools and service-learning projects into their teaching effectively. This could include workshops, collaborative planning, and resources that emphasise integrating technology and sustainability in educational settings.

5.2. Limitations

This study has several limitations. First, the sample was confined to a specific group of students, which may limit the generalizability of the findings. Additionally, the use of self-reported data introduces the possibility of bias, as students may have provided socially desirable responses rather than fully accurate reflections of their knowledge, attitudes, or experiences. Future studies should address the limitations of this research by using a more diverse and representative sample to increase the generalizability of the findings. Researchers could incorporate objective assessments such as observations or performance-based tasks to minimise biases from self-reported data.

5.3. Recommendations

On the basis of these findings, the following recommendations are made:

1. Schools should incorporate AI-powered tools into the curriculum to enhance student engagement and understanding of sustainability and green materials.
2. The opportunities for students to participate in AI-supported service-learning projects focused on sustainability issues should be increased.
3. Provide professional development for teachers to use AI tools effectively and design impactful service-learning projects.
4. Schools should broaden students' exposure to green technologies such as nanotechnology and renewable energy through partnerships and hands-on experiences.

Acknowledgement

The authors express sincere gratitude to the school heads, teachers, and students who participated in the study for their time and cooperation. Special thanks are extended to colleagues and research assistants who contributed through insightful feedback, data collection, and transcription support.

Ethical Considerations

Ethical approval for this study was obtained from the Research Ethics Committee of the Faculty of Education, University of Nigeria, Nsukka, and informed consent was obtained from all participants. The study adhered to all ethical guidelines for research involving human subjects, including confidentiality, voluntary participation, and the right to withdraw at any time.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Funding

This research did not receive any financial support.

References

Adedara, T. S. (2021). *Effect of service-learning instructional strategy on students' knowledge and attitude to social vices concepts in civic education in Ondo State* [Master's thesis, University of Ibadan].

Alalade, O. E. (2023). Effect of service and collaborative learning strategies on learners' environmental attitude. *International Journal of Environmental, Sustainability, and Social Science, 4*(4), 1270–1278. https://doi.org/10.38142/ijesss.v4i4.647

Begum, A., Liu, J., Marwat, I. U. K., Khan, S., Han, H., & Ariza-Montes, A. (2021). Evaluating the impact of environmental education on ecologically friendly behavior of university students in Pakistan: The roles of environmental responsibility and Islamic values. *Sustainability, 13*(18), 10188. https://doi.org/10.3390/su131810188

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.

Egara, F. O., & Mosimege, M. (2023a). Effect of flipped classroom learning approach on mathematics achievement and interest among secondary school students. *Education and Information Technologies, 29*(7), 8131–8150. https://doi.org/10.1007/s10639-023-12145-1

Egara, F. O., & Mosimege, M. (2023b). Students' perceptions of mathematics teachers' usage of ethnomathematics materials in the teaching and learning of mathematics. *International Journal of Multicultural Education, 25*(2), 443–459.

Egara, F. O., & Mosimege, M. (2024). Exploring the integration of artificial intelligence-based ChatGPT into mathematics instruction: Perceptions, challenges, and implications for educators. *Education Sciences, 14*(7), 742. https://doi.org/10.3390/educsci14070742

Egara, F. O., Mosimege, M., & Mosia, M. (2025). Secondary school students' perceptions of their usage of artificial intelligence-based ChatGPT in mathematics learning. *Journal of Education, 98*, 124–146. http://dx.doi.org/10.17159/2520-9868/i98a07

Egbezor, D. E., & Brisk-Elemele, J. (2016). The influence of environmental education on the behavior of senior secondary school students in Port Harcourt metropolis. *International Journal of Education and Evaluation, 2*(2), 51–65.

Filges, T., Dietrichson, J., Viinholt, B. C. A., & Dalgaard, N. T. (2022). Service learning for improving academic success in students in grade K to 12: A systematic review. *Campbell Systematic Reviews, 18*(1), 1–36. https://doi.org/10.1002/cl2.1210

Gupta, M. S., Samrutwar, A. M., Rahandale, A. M., & Edlabadkar, A. A. (2024). The influence of environmental education on college students' behavioural attitudes towards sustainability. *Journal of Learning and Educational Policy, 4*(6), 48–58. https://doi.org/10.55529/jlep.46.48.58

Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. Centre for Curriculum Redesign. https://curriculumredesign.org/wp-content/uploads/AIED-Book-Excerpt-CCR.pdf

Kizildeniz, T., & Bozkurt, F. (2024). Evaluating climate change knowledge, attitudes, and behaviors (KAB) in agricultural sciences and technologies education. *Karadeniz Fen Bilimleri Dergisi, 14*(2), 619–633. https://doi.org/10.31466/kfbd.1400642

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Komalasari, K., & Saripudin, D. (2019). Service learning model in social studies to foster student social care. *The New Educational Review, 56*(2), 204–214. https://doi.org/10.15804/tner.2019.56.2.17

Mahinay, H. A. C., Marapao, M. S. A., Jempero, J. B., & Allawan, J. G. L. (2023). Environmental literacy and pollution awareness among senior high school students in the Philippines. *Journal of Environmental Impact and Management Policy, 3*(6), 17–25.

Milfont, T. L., & Duckitt, J. (2010). The Environmental Attitudes Inventory: A valid and reliable measure to assess the structure of environmental attitudes. *Journal of Environmental Psychology, 30*(1), 80–94. https://doi.org/10.1016/j.jenvp.2009.09.001

Mohamed, M. Z. bin, Hidayat, R., Suhaizi, N. N. binti, Sabri, N. binti M., Mahmud, M. K. H. bin, & Baharuddin, S. N. binti. (2022). Artificial intelligence in mathematics education: A systematic literature review. *International Electronic Journal of Mathematics Education, 17*(3), em0694. https://doi.org/10.29333/iejme/12132

Mosia, M., Egara, F. O., Nannim, F. A., & Basitere, M. (2025). Factors influencing students' performance in university mathematics courses: A structural equation modelling approach. *Education Sciences, 15*(2), 1–16.

Okeke, A. M., Egara, F. O., & Mosia, M. (2025). The Van Hiele model's effects on student attitudes and achievement in geometry content of senior secondary mathematics. *International Journal of Pedagogy and Curriculum, 32*(1), 81–105. https://doi.org/10.18848/2327-7963/CGP/v32i01/81-105

Okeke, A. M., Egara, F. O., Orga, A. C., & Nzeadibe, A. C. (2023). Effect of symbolic form model on students' interest in logic content of the mathematics curriculum. *Pedagogical Research, 8*(2), em0159. https://doi.org/10.29333/pr/13077

Olajire, A. A. (2020). Environmental literacy: Comparative analysis of public and private junior secondary school students in Southwest Nigeria. *East African Scholars Journal of Education, Humanities and Literature, 2*(5), 1–9.

Osakwe, I. J., Egara, F. O., Inweregbuh, O. C., Nzeadibe, A. C., & Emefo, C. N. (2022). Interaction patterns: An approach for enhancing students' retention in geometric construction. *International Electronic Journal of Mathematics Education, 18*(1), em0720. https://doi.org/10.29333/iejme/12596

Roco, M. C., & Bainbridge, W. S. (2013). *The new world of discovery, invention, and innovation: Convergence of knowledge, technology, and society*. Springer. https://doi.org/10.1007/978-3-319-02204-7

Samino García, R. (2023). A service-learning program assessment: Strengths, weaknesses, and impacts on students. *Intangible Capital, 19*(1), 4–24. https://doi.org/10.3926/ic.2093

Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2011). Students' conceptions about the greenhouse effect, global warming, and climate change. *Climatic Change, 104*(3), 481–507. https://doi.org/10.1007/s10584-009-9786-9

UNESCO. (2019). *Education for sustainable development: A roadmap*. United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000370215

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wandera, E., Edward, A., Atibuni, D. Z., & Suubi, M. S. U. (2022). Environmental literacy and the practice of sustainability among secondary school students in Busia District, Uganda. *East African Journal of Education Studies, 5*(2), 1–12. https://doi.org/10.37284/eajes.5.2.644

Zahedi, S., Jaffer, R., Bryant, C. L., & Bada, K. (2023). Service-learning effects on student civic engagement and community: A case study from India. *Education, Citizenship and Social Justice, 18*(1), 3–21. https://doi.org/10.1177/17461979211041334

Zhang, J., Tong, Z., Ji, Z., Gong, Y., & Sun, Y. (2022). Effects of climate change knowledge on adolescents' attitudes and willingness to participate in carbon neutrality education. *International Journal of Environmental Research and Public Health, 19*(17), 10655. https://doi.org/10.3390/ijerph191710655