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Cultivating sustainability-minded accountants using an artificial intelligence (AI) powered personalized learning tool for enhancing accounting education

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Abstract

Amid increasing global sustainability emphasis, there have been calls for universities to integrate sustainability into teaching curricula. Specifically, accounting disciplines are expected to groom and produce sustainability-conscious graduates, owing to accountants' recognition as key players in advancing sustainable practice. Yet traditional accounting continued to struggle with integrating sustainability education, leaving students and graduates ill-equipped with the necessary skills to address sustainability challenges in the workplace. Using an AI-powered personalized pedagogical chatbot tool, this study introduces undergraduate accounting students to sustainability accounting concepts. Thereafter, we examined the chatbot's effectiveness in enhancing sustainability accounting education to foster sustainability-conscious accountants. Guided by constructivist and human capital theories, the study employed a single-group pre-test/post-test pre-experimental design and survey instrument to gather perception-based data from 203 students at Kwara State University in Nigeria. Findings revealed a low baseline knowledge about sustainability accounting prior to chatbot intervention and a significant improvement in student performance post-intervention, indicating the chatbot was instrumental in fostering sustainability knowledge. Additionally, confirmation that the tool fosters active learning, knowledge and skills development, and enhanced employability value. This study contributes to sustainability accounting education and aligns with Sustainable Development Goals (SDGs) 4 (quality education), 9 (industry, innovation, and infrastructure), and 17 (partnerships for the goals). The study lends credence to aligning digital transformation with sustainability literacy, offering a transformative solution to the challenges of sustainability practice in the realm of accounting education in an emerging context. It has implications for higher institutions, government, education regulators, ministries, and professional bodies.

Keywords Sustainability accounting, Curriculum development, Higher education, educational technology, Student engagement, Accounting education, Developing country

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1 Introduction

Teaching sustainability development in higher educational institutions (HEIs) has become essential for future professionals [32]. This is due to the increasing urgency to address complex environmental, social, and governance (ESG) issues linked to climate change (CC) and sustainable development. The expectation is even more pronounced for accounting professionals because been custodians of corporate disclosure and reporting systems, accountants are now key players in advancing sustainability reporting and responsible business practices [8, 25, 26, 29, 38, 49]. This shift aligns with the United Nations Sustainable Development Goals (UN-SDGs), which demands quality education and innovation-focused learning systems that can facilitate sustainable transformation [48].

Despite the increasing global advocacy and professional emphasis for sustainability-focused learning, sustainability content remains unevenly integrated into accounting curricula [40, 44]. Empirical evidence suggests that barely 11% of accredited accounting programs globally offer courses that integrate sustainability learning objectives, indicating limited curricular adoption [17, 52, 53]. This gap is even more pronounced in developing countries such as Nigeria, where the accounting education curriculum continues to focus largely on traditional accounting subjects like financial reporting, taxation, and auditing, with limited or no emphasis on sustainability accounting [14, 25, 26, 37, 40, 44, 48]. Consequently, many graduates are left unexposed to requisite sustainability knowledge needed for professional practices [20, 25].

Alongside the sustainability requirement, higher education is also experiencing rapid digital transformation owing to the advent of artificial intelligence (AI). AI-powered pedagogical tools like chatbots, intelligent tutoring systems, and adaptive learning platforms are increasingly employed for delivering personalized feedback, enhance engagement, and support self-regulated learning [3, 63]. Emerging research in accounting education suggests that a chatbot-based systems can improve students' self-regulated learning, motivation, adaptability, and conceptual understanding [2, 6, 47]. These attributes are essential for navigating the future workplace. However, empirical evidence on AI-enabled sustainability accounting instruction remains concentrated in developed contexts yet limited in African higher education while it is close to non-existence within Nigeria.

These significant contextual gaps call for empirical work within the Nigerian context, an environment often characterized with limited resources, low-level of digital literacy, and infrastructural constraints. Hence, the motivation for the current study to examine whether a chatbot-based learning intervention can enhance undergraduate accounting students' knowledge of sustainability accounting concepts in a Nigerian university setting. Beyond the knowledge gains, the study also specifically assesses students' perceptions of the chatbot as a pedagogical tool. Therefore, the study pursues the below three objectives:

i. Assess students' baseline knowledge of sustainability accounting concepts and their performance before the intervention of the AI-powered chatbot.
ii. Evaluate the effectiveness of the chatbot in enhancing students' knowledge post-intervention.

iii. Assess students' perceptions about the chatbot efficacy as a pedagogical tool for integrating sustainability concepts into accounting education.

The objectives were addressed through the following research questions:

RQ1: What is the baseline knowledge level of students about sustainability accounting concepts, and students' performance before the intervention of the AI-powered chatbot?

RQ2: How effective is the chatbot in enhancing students' knowledge post-intervention?

RQ3: How do students perceive the chatbot efficacy as a pedagogical tool for integrating sustainability concepts into accounting education?

The study draws on a combination of constructivist learning theory (CLT) of Piaget [51] and Vygotsky [64], which argues that individuals construct active knowledge through interaction and reflection, and human capital theory (HCT) by Becker [12] and Schultz [54] which presents education as an investment in professional competence development. These theoretical foundations are operationalized by the chatbot, by providing structured, interactive exposure to sustainability accounting concepts within a controlled instructional setting. Through this methodological approach, the study broadens the agenda of reimagining accounting education in line with SDGs 4, 9, and 17, promoting inclusive learning, digital innovation, and partnership.

This study therefore makes two significant contributions to literature. First, the study offers empirical evidence on AI-focused sustainability accounting instruction in a context where both sustainability integration and digital pedagogies remain under-developed. Second, it provides practical insight for curriculum designers and educators seeking scalable approaches to embedding sustainability content in accounting programs within a resource-constrained contexts.

The remainder of the sections are structured as follows: The next section provides reviews of relevant literature and develops the conceptual framework. Subsequent sections detailed the methodology, next present the results, this is then followed by the discussion, conclusion, and and limitations.

2 Literature review

2.1 Sustainability integration into accounting education

The integration of sustainability into accounting education reflects a wider shift in accountants' role. As corporate reporting increasingly incorporates ESG disclosures, accounting professionals are expected to evaluate, analyze, interpret, and assure non-financial information in addition to traditional financial metrics [14, 26]. This transformation has ignited calls for accounting curricula to align with evolving professional standards and sustainability-oriented reporting frameworks.

HEIs are therefore now incessantly pressured by professional bodies, regulators, and the public to groom accountants who are environmentally conscious and possess the requisite knowledge to integrate sustainability principles into corporate decision-making likewise integrate sustainability competencies within accounting programmes [32]. Such integration extends beyond merely adding discrete topics as it necessitates reconsidering learning objectives to incorporate ethical reasoning, stakeholder accountability, and systems thinking [57]. It is vital to note that when effectively integrated, graduates of sustainability accounting education programmes will be better equipped to interact with integrated reporting, carbon disclosure, ESG measurement, and sustainability assurance practices.

Empirical evidence, however, indicates that integration remains uneven among institutions and jurisdictions. In many contexts, students' systematic exposure to sustainability accounting principles is often limited due to sustainability content either being offered as an elective or marginally integrated into already-existing courses [14, 36].

2.1.1 Benefits of sustainability accounting education

Sustainability-focused accounting education provides both professional and pedagogical advantages. Professionally, capital markets investment decisions continuously require ESG disclosures. As a result, the demand for accountants who can interpret sustainability metrics and reporting standards is increasing [35]. Hence, graduates trained in sustainability accounting are better positioned to support integrated reporting initiatives and respond to employer demand for ESG-related expertise [17].

Meanwhile, in terms of pedagogical benefits, embedding sustainability fosters higher-order learning. Reason because exposing students to sustainability topics like carbon accounting, green investment, reporting on circular economy, and sustainability performance measurement will promote analytical reasoning and multidimensional problem-solving [32]. Instead of concentrating solely on compliance-based financial reporting, students engage with real-world trade-offs between financial performance and societal impact.

Additionally, ethical awareness and stakeholder-oriented thinking, which are widely recognized as core professional competencies are strengthened by sustainability education [57]. When properly integrated, it fosters graduates who can navigate the financial and non-financial aspects of corporate accountability.

2.1.2 Challenges of sustainability accounting education

Despite the proclaimed benefits, sustainability integration into accounting education is faced with structural and institutional constraints, particularly in developing countries. One significant barrier is curriculum rigidity. Many of the accounting programmes across HEIs in developing countries adhere strictly to curricula requirements set by accrediting bodies (education ministries and professional bodies) that prioritize technical competencies in financial reporting, taxation, and auditing over sustainability competencies [32, 48]. For instance, in Nigeria, universities operate under the strict oversight of the National Universities Commission (NUC), that prescribes benchmark minimum academic standards. While this commission ensure standardization, they may limit curricular flexibility to incorporate emerging sustainability topics unless explicitly mandated. Meanwhile, professional accounting bodies influence course structures through accreditation and examination requirements, that also sometimes remain focused in traditional accounting domains.

Resource constraints further limits integration. Oftentimes, developing countries are faced with poor funding, lack of digital infrastructure, and limited faculty training opportunities [4, 5]. While, sustainability accounting requires interdisciplinary expertise, many instructors have limited experience with ESG reporting frameworks or sustainability measurement tools [14]. Evidence also stressed reservations around existing pedagogy and faculty reluctance to engage in sustainability issues, especially in cases where sustainability is perceived as incidental to core accounting knowledge [40].

Conceptual fragmentation presents another layer of challenge. Linking ethical theory, environmental measurement, and financial reporting standards is necessary for sustainability accounting. However, sustainability is often handled as though it is a stand-alone topic rather than integrated across financial, managerial, and auditing courses without coherent curriculum mapping [36]. Meanwhile, students' ability to link sustainability disclosures to broader accounting systems is weakened by this fragmentation. At the institutional level, lack of strategic direction and limited leadership commitment may widen the gap between policy rhetoric and classroom practice [4, 5]. Universities however may endorse sustainability in their mission statements without incorporating it structurally into their programme designs.

To ensure that sustainability accounting become a core rather than an incidental part of accounting education, curriculum reform, faculty development, and accreditation alignment are critical. Therefore, addressing these barriers requires collaboration among university administrators, NUC, and professional accounting bodies.

2.2 AI-personalized pedagogy tool and sustainability accounting education

AI-personalized pedagogy tools, particularly chatbots, are increasing employed in higher education to support adaptive and interactive learning. A chatbot is an intelligent conversational tool capable of simulating dialogues, offering users instant feedback to queries, provide adaptive instruction, and foster continuous learner engagement [39, 47, 63]. Chatbots unlike static digital tools enable iterative exchanges, allowing students to refine questions, test understanding, and receive context-sensitive explanations.

Within accounting education, chatbots serve as modern interactive tools for teaching abstract and technical concepts. They provide actionable content and let students learn through online messaging in a similar way to how they would prompt and facilitate a continuous conversation [41]. Through its conversational interaction, it can scaffold complex accounting topics by breaking them into manageable explanations and guide the students through logical reasoning processes. Moreover, through iterative dialogue and scenario-based prompts, it offers students the opportunity to practice real-time knowledge gained and apply accounting principles while receiving immediate feedback, which is particularly relevant for fostering sustainability-minded accountants [10].

The pedagogical value of chatbot-based learning lies in three attributes. First, prompt feedback facilitates knowledge consolidation and error correction. Second, adaptive interaction promotes self-regulated learning by allowing learners to grow at their own pace. Third, compared to passive lecture formats, chatbots conversational engagement may boost cognitive involvement [21, 55]. Research indicates that when properly designed, AI-supported instruction can enhance retention level, engagement, and conceptual understanding [7].

Besides, for emerging nations like Nigeria, integrating chatbots into sustainability education can assist in overcoming some of the challenges posed by traditional teaching. For instance, the longstanding barriers like resource constraints, large class sizes, and poor learning engagement can be addressed if institutions leverage AI chatbots. As noted by De Simone et al. [21], chatbots and other generative AI tools have the potential to advance education in Sub-Saharan Africa by increasing access to personalized education support. Similarly, Suleiman et al. [59] emphasized that chatbots and other AI digital tools can boost student satisfaction, increase communication effectiveness, and facilitate

real-time learning support for Nigerian students. Obiwuru, [46] also stressed that chatbots can enhance digital literacy, create an avenue for effective feedback, and improve student-teacher interaction, especially where there is adequate institutional support and faculty willingness.

These attributes are particularly relevant to sustainability accounting context because complex sustainability topics like carbon accounting, ESG performance measurement, and integrated reporting require multidimensional reasoning and cross-domains application of principles. By allowing students to test interpretations, ask for clarifications, and work through contextual examples, interactive tools can facilitate exploratory learning. Additionally, technology-enhanced training has been linked with gains in digital literacy, critical thinking, and adaptability, essential competencies increasingly demanded in sustainability-oriented professional environments [6].

Therefore, integrating sustainability concepts into accounting education through technologies will assist in reducing barriers to participation and promoting student-focused learning, consequently, contributing to inclusive and sustainable learning. By integrating these tools into sustainability education, self-regulated and reflective learning that is vital for accounting professionals' ethical and professional development will be fostered.

Despite these benefits empirical evidence on AI-enabled sustainability accounting education remains limited, particularly in developing contexts. Although research from developed nations shows that chatbot-based systems improve learning outcomes [7], context-specific evidence from African HEIs is still scarce. In Nigeria, where accounting programmes are often characterized by large class sizes, resource constraints, and limited instructional support, AI-enabled tools may provide scalable instructional support. Yet there is a dearth of systematic assessments of their efficacy within sustainability-oriented accounting instruction.

Based on the foregoing, examining chatbot-assisted sustainability accounting education within a Nigerian university context offers an opportunity to assess both pedagogical efficacy and contextual feasibility. To ascertain if such tools significantly enhance knowledge acquisition and student learning experiences in sustainability accounting, empirical testing is required rather than assuming technological benefits.

2.3 Theoretical framework

This study anchors on constructivist learning theory (CLT) and human capital theory (HCT) to explain both the pedagogical processes and expected developmental outcomes of incorporating sustainability accounting content into an AI-supported learning environment. While CLT offers a process-oriented explanation through which students actively construct and assimilate knowledge, HCT provides an outcome-oriented justification of the importance of such educational investment. Together, these perspectives present the chatbot intervention as a strategy for developing human capital as well as a learning tool.

2.3.1 Constructivist learning theory

CLT, which has its foundation rooted in the works of Piaget [51] and Vygotsky [64], posits that learners construct knowledge through active engagement, reflection, and social interaction and not by mere absorption of passive information. Learning occurs when individuals link newly acquired information to past knowledge and continuously

improve their comprehension through discussions and feedback [11]. This theory strongly emphasises a learner-centered approach, experiential pedagogies, particularly for complex and abstract subjects. The argument that this theory promotes is essential to sustainability accounting, which requires integration of financial, ethical, and environmental reasoning [37, 53].

AI-personalized chatbot align with CLT principles in several ways. First, conversational interaction promotes iterative questioning and clarification. Second, instant feedback promotes cognitive improvement and error correction. Third, adaptive responses allow students to progress based on their comprehension level. Through repeated interactions, students actively test and refine their understanding of sustainability concepts rather than rote memorizing of definitions, making it crucial for assimilating and building sustainability-oriented thoughts in accounting practice [3, 63].

In this regard, the chatbot functions as a mediating tool that allows for reflective engagement with sustainable accounting content. It promotes self-regulated learning and critical reasoning, both of which are essential components of constructivist pedagogy.

2.3.2 Human capital theory

HCT advanced by Becker [12] and Schultz [54], views education as an investment that increases individuals' productive ability and long-term economic value. According to HCT, educational acquisition increases employability, adaptability, and societal contribution by developing relevant skills and competencies. Hence, education is not a mere individual good, rather a strategic tool. Applied to accounting education, HCT argues that curriculum design should respond to evolving needs of sustainability-driven businesses and professional demands. As sustainability reporting and ESG disclosures gain popularity, accounting graduates need competencies that goes beyond traditional financial reporting to be employable. Therefore, integrating sustainability accounting into curricula represents an investment in workforce relevance and professional adaptability [26, 49].

Within this framework, chatbot intervention serves as a mechanism for skill development. By fostering conceptual understanding, critical thinking, analytical reasoning, and digital engagement, the AI-personalized platform contributes to the development of competencies valued in sustainability-oriented labour markets [4, 5, 27]. Therefore, universities can leverage this adaptive pedagogy tool to effectively bridge existing competency gaps [17, 25].

While CLT explains how learning take place within the chatbot-supported environment, HCT clarifies why such learning is crucial beyond the classroom. Also, the former emphasizes interactive knowledge construction while the later highlights the economic and professional value of the competencies developed i.e., grooming graduates who are socially and economically responsible. By applying both theories and incorporating sustainability accounting content within an AI-personalized pedagogy tool, this study positions educational innovation as both pedagogically grounded and economically significant. The framework thus connects instructional design (constructivist engagement) to expected outcomes in knowledge acquisition and professional competency (human capital building).

2.4 Literature gap

Prior works on sustainability accounting education has predominantly concentrated on sustainability reporting, curriculum design, and sustainability standards settings [32, 48]. While these studies reinforce the significance of integrating sustainability within accounting education, they mostly adopt conceptual or policy-oriented approaches rather than empirically testing instructional innovations. Similarly, empirical evidence on AI in accounting education have considered its role in improving technical knowledge gain, assessment effectiveness, and digital competence [6, 7]. However, this stream of research has generally focused on conventional accounting areas, with limited attention given to sustainability-focused content.

Therefore, two significant voids exist in the literature. First, there is scant empirical evidence of the efficacy of AI-powered personalized pedagogical tools in teaching sustainability accounting. Although sustainability integration and AI adoption have been examined separately, their intersection remains unexplored. Second, contextual evidence from emerging climes, particularly for Nigeria where there exist limited digital infrastructures and accounting programmes adhere to centralized curricular requirements is close to non-existent. Neither has existing studies evaluate AI-supported sustainability training for enhancing accounting education in this context nor examine how students perceive AI-personalized tools for similar purpose. This study, therefore, fills a significant void by empirically evaluating how AI-powered personalized chatbot can be leveraged to enhance accounting education and foster sustainability-conscious accountants within a Nigerian university context. Through integrating pedagogical theory with contextual analysis, the study contributes to debate on both instructional effectiveness and feasibility in an emerging economy setting.

Figure 1 depicts the study's conceptual framework.

3 Study context/design

3.1 Research design

This study employed a single-group repeated-measures intervention design (i.e., a one-group pre-test/post-test pre-experimental design) combined with a cross-sectional survey, conducted under a controlled supervised classroom condition. Typically, the absence of a comparison group would align the study structure with what Campbell and

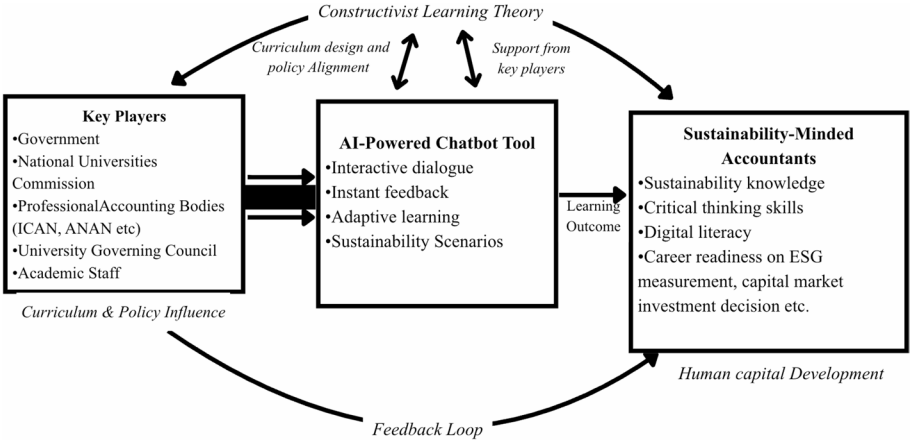


Fig. 1 Conceptual framework for AI-personalized Chatbot for cultivating sustainability-minded accountant

Stanley [13] classifies as a pre-experimental design. However, the current study implemented several procedural controls to strengthen internal validity. This includes supervised implementation, restricted access to external learning resources including web contents, controlled platform access, and delayed post-testing. Research suggests that when pre-experimental design are implemented with procedural controls, the design remains a robust approach for preliminary evaluation of instructional interventions [9, 56, 62]. This approach was selected because of it allows for preliminary assessment of learning gains following an instructional intervention. Hence, its suitability for evaluating the cognitive impact of the AI-powered personalized learning chatbot and students' perception about its effectiveness in fostering sustainability-minded accountants. This mixed approach allowed for the investigation of respondents' attitudinal responses as well as the assessment of change over time (pre- vs. post-intervention). While the pre-test and post-test evaluated students' objective acquisition of knowledge, the survey instrument measured subjective learning experiences and the perceived value of the AI tool.

3.2 Population, sampling, and consent

The study was conducted in Kwara State University, located in the vibrant city of Malete, Moro Local Government Area (LGA) of Kwara State, notable for its rural and agricultural economy in Western Nigeria. Using a purposive sampling technique, respondents comprised third year undergraduate accounting students, mainly between the ages of 18 and 25years. This student cohort was selected because at this stage of the programme, students are believed to have a solid grasp of the accounting concepts they have been taught from their early years at the university. Students at this level are usually exposed to intermediate and advanced accounting courses, where conceptual understanding, analytical reasoning, and applied problem-solving skills become increasingly crucial [19, 58]. As a result, transitioning from theoretical to applied learning is more visible at this stage. We believe the foundational experience of these students prepares them to interact with the AI chatbot in a meaningful way and offer insightful feedback on its value. Prior research has shown that advanced undergraduate students display increased capacity for metacognitive reflection of their educational experiences, developmentally positioning them to critically engage with instructional cutting-edge technologies and reflect on their efficacy [24, 45]. Therefore, given this study's research design, focusing on this student cohort mitigates the risk of confounding factors attributed to novice-level exposure that early years students often showcase or exam-related pressures typical among final-year students. Hence, our choice of purposive sampling allowed us to specifically select respondents with certain knowledge, experience, and learning exposure necessary to address the research objectives. This approach guarantees more consistent engagement and reliability of responses.

Although all third-year accounting students in the population (N = 238) was targeted, a few were unable to partake due to limited internet access and a lack of mobile devices, leaving a final sample size of 203 students, making a response rate of 85%. Studies in social science suggest that response rates above 70% are generally regarded as strong and indicative of reduced non-response bias when sampling a defined cohort [22, 30]. The final sample comprised 82 males and 121 females. All respondents gave their informed

consent, participation was entirely voluntary, and necessary ethical clearance was obtained, consistent with standard research practice in educational studies [18].

3.3 Research instrument

3.3.1 Pre and post-intervention test

The pre- and post-test questions comprised a 30-item structured knowledge test, with core content on sustainability accounting concepts. All questions were allocated a score of 1 for each correct response and 0 otherwise, making the maximum obtainable score point equal 30. The test items prior to administering were subject to content validation by experts comprising two professors of accounting education and a sustainability reporting specialist. Based on the feedback received from validation testing, a few changes were made to enhance item clarity and cognitive balance. Each respondent was given a unique identifier code to enable easy matching of the pre-test and post-test scores, likewise the survey responses. The administration pre-and post-intervention lasted for about six weeks.

3.3.2 The chatbot learning intervention: operation and contents

The core intervention used in the study is an AI-powered personalized learning chatbot. We integrated sustainability accounting concepts into the chatbot that we created using an open educational AI interface. Hence, it served as a virtual tutor that provided adaptive learning, personalized feedback, and interactive prompts to the students. The chatbot contents were subject to validation by experts in accounting education and AI pedagogical tools.

For the chatbot operation, once it is launched, it welcomes a learner asking them to input their name (See Fig. 2). Once the learner responds and click ok, they are prompted with a question on whether they have prior knowledge about sustainability accounting or not (See Fig. 2). Depending on the learners' response choice, they are further guided by the chatbot following every prompt conversationally through generated text. For instance, if a learner responds 'no' to not having prior knowledge of the concept, a new conversation prompt leads the learner to different aspects of the sustainability concept they could learn as a beginner. A similar conversation prompt is also provided if the learner responds 'yes' (see Fig. 2) with varying sustainability topics covered for advanced

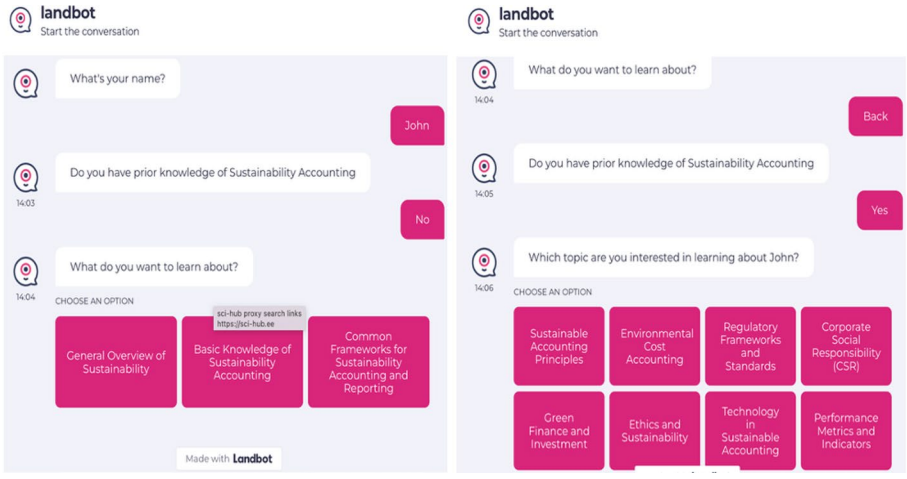


Fig. 2 Home and introductory screen

learners. The topics were carefully drafted and integrated into the chatbot such that learners are provided with detailed background knowledge that provides them with comprehensive insights into the essence of sustainability accounting and its relevance to accountants.

The chatbot content was designed to cover topics such as a general overview of sustainability accounting, common frameworks employed for sustainability reporting, sustainability principles, environmental cost accounting, green finance and investment, International Financial Reporting Standard on Sustainability-related risks and opportunities (IFRS S1), and Climate-related Disclosures (IFRS S2).

For every topic discussed, there were knowledge tests that learners attempted with immediate feedback provided. The knowledge test assesses what the students learnt/gained from each of the conversations using real-world scenarios so that they can relate it to practical cases (see Fig. 3). Immediate feedback was provided on whether the response was right or wrong. For every wrong response, the student is allowed to go through the lessons again for as long as they require to have a good grasp of the concepts before proceeding to a different topic.

3.3.3 Survey instrument

The developed survey instrument employed in this study measures students' perception regarding the efficacy of the chatbot as a pedagogical tool for learning sustainability accounting. It consisted of 14 items (see Table 1) split into three sub-dimensions measured on a 5-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree.

The first dimension, which comprised five items, measured the perceived improvement in conceptual understanding and analytical skills of the respondents centered on knowledge and skills development. The second dimension consisted of four items assessing the chatbot's perceived relevance to employability, professional value, and the importance of sustainability literacy. This dimension concentrated on employment and value enhancement. The third dimension, which concentrated on active learning engagement, included five items that measured how the chatbot motivated the students' learning experience, fostered engagement, and sense of interactivity.

To ensure content relevance, clarity, and construct coverage, the questionnaire, prior to administering it, was reviewed by three experts comprising: a senior accounting

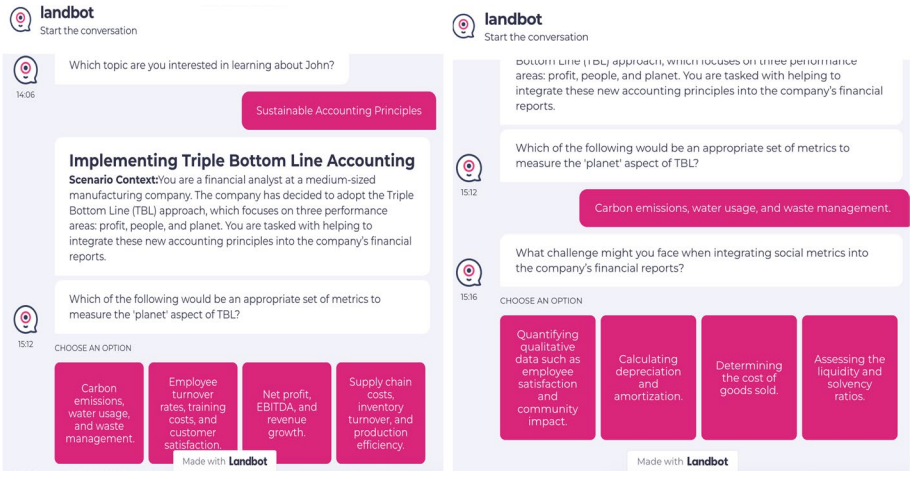


Fig. 3 Chatbot knowledge test screen samples

Table 1 Questionnaire items

Codes	Knowledge and skill development
KS1	The chatbot effectively helps me understand the basic principles and retain key concepts about sustainability accounting.
KS2	Using the chatbot has improved my ability to interpret sustainability accounting metrics.
KS3	The chatbot helps me apply sustainability accounting concepts to real-world scenarios.
KS4	The chatbot provides relevant case studies and examples in sustainability accounting.
KS5	The chatbot has enhanced my ability to critically analyse sustainability accounting reports.
Perceived employability and value	
EV1	The chatbot gave me valuable insights into complex sustainability accounting topics, which I hope to apply in my future job.
EV2	It was a valuable addition to my knowledge of current trends in the accounting field, and I believe it is relevant for my long-term professional growth.
EV3	I would recommend the chatbot to other students.
EV4	The chatbot improved my overall learning experience.
Active learning engagement	
AL1	The chatbot's interactive features helped me to engage well with sustainability accounting material.
AL2	The chatbot simplified sustainability accounting principles.
AL3	I find it easy learning about sustainability accounting concepts by interacting with the chatbot.
AL4	It was very easy to follow the chatbot's explanations on sustainability accounting concepts.
AL5	The chatbot approach made self-directed learning easier.

educator, a psychometrist, and an educational technologist. Their valuable suggestions helped to improve the logical sequencing and clarify unclear items.

3.4 Data collection procedure

The study data were gathered across three phases:

3.4.1 Phase one

Here, respondents received and completed the 30-item pre-test questions designed to measure and establish their baseline knowledge and understanding of sustainability accounting concepts and principles.

3.4.2 Phase two

This is the intervention phase, where students were introduced to the chatbot and provided with access to the application link. Students engaged and interacted with the tool using their mobiles in guided exercises over four-weeks, with a self-paced knowledge test showcasing practical scenarios of sustainability case discussions, allowing them to learn about the core of sustainability accounting concepts and principles. In this phase, the chatbot contained formative quizzes after each topic, embedded within case-study scenarios. The quiz items were context-specific and directly linked to the cases presented on the chatbot platform, the formative quizzes were not the same as the 30-item pre/post knowledge test. The internal quizzes were created as formative evaluations to reinforce conceptual understanding through scenario-based applications. The 30-item instrument only served as a standardized summative measure of knowledge gain. Although both instruments assessed core sustainability accounting concepts and principles, yet they differed in structure, wording, and item sequencing in order to reduce direct item rehearsal effects. Specifically, this distinction was to ensure construct alignment while avoiding direct item overlap.

Meanwhile, the chatbot intervention was carried out in a supervised academic classroom environment, typical of a standard university examination condition. Specifically, due to limited trial access to the chatbot application, student usage was controlled via restricted login attempts with single-sign-on device access, each student assigned a unique session link that could not be reused or shared to another student. The chatbot access including pre-test/post-test links were all shared strictly during scheduled lecture time, during which the respondents were closely monitored to ensure they had no access to any external sustainability accounting materials such as textbooks, web resources, peer discussions, or other independent digital devices. Upon completion of each session, students were logged out permanently without further access to re-use any of the links.

3.4.3 Phase three

Here is the completion stage, where respondents re-attempt the same questions from the pre-test and complete the survey questionnaire to give their perception of the AI-chatbot pedagogical tool. Although, the same 30-item knowledge test was administered at pre-test and post-test to ensure measurement consistency. However, students were not provided with feedback or answer keys after the pre-test. In addition, a six-week interval between the pre-test and post-test and the absence of feedback was maintained to reduce short-term recall and practice effects. Educational measurement studies suggests that having a longer interval between repeated test administrations reduces the likelihood of item-specific memory that influences subsequent responses [42, 66]. While practice effects cannot be fully eliminated in repeated-testing designs, these measures were taken to mitigate their influence.

The four-week interval between the pre-test (Phase One) and chatbot engagement (Phase Two), as well as the additional two-week interval between the intervention and the post-test (Phase Three), were incorporated specifically to reduce short-term recall effects and minimize potential testing bias. Furthermore, to minimize human administrative error and ensure standardization, all instruments were distributed electronically using Google Forms.

3.5 Method of data analysis

We conducted all analyses using IBM SPSS Statistics (version 29), covering both descriptive and inferential statistics. To summarize trends in students' performance and attitudes, descriptive statistics such as means, standard deviations, minimum, and maximum were calculated for the pre-test, post-test, and perception dimensions. For reliability of scale and internal consistency, we computed the Cronbach's alpha values for individual sub-scales and for the total perception constructs [60]. Meanwhile, prior to the main analysis, both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were conducted to verify the construct validity (i.e., dimensional structure) of the instrument. The Bartlett's test of sphericity was statistically significant ($p < 0.001$), indicating suitability of the data for factor analysis and Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy had a value of 0.82 exceeding the recommended threshold of 0.70 [34]. Based on principal axis factoring with oblique rotation, a three-factor solution emerged consistent with the theoretically proposed dimensions: knowledge and skill development, employability and professional value, and active learning engagement. All previous items that had low factor loadings or substantial cross-loadings

were removed during the scale refinement process to ensure factorial clarity while all the retained items loaded strongly on their respective factors and exhibited minimal cross-loadings.

Although, some retained items appear to address related aspects of learning, but the subsequent factor analysis results (CFI = 0.96, TLI = 0.92, RMSEA = 0.058, SRMR = 0.04), indicated acceptable model fit, confirming that the final retained items represent empirically distinguishable but conceptually complementary dimensions.

For inferential analysis, we employed a one-sample t-test to compare the pre-test mean score to the expected baseline proficiency level. To assess learning improvement attributable to the AI chatbot, a paired-sample t-test comparing pre-test and post-test means is used. The effect size of the observed improvement was calculated using Cohen's d. Furthermore, a descriptive statistic was employed to explain differences based on the mean of students' perception across the three constructs of knowledge and skills, employment and value, and active learning examined by the survey.

For visual presentation of spread and direction of learning impact, we plotted the histogram and we had a Q-Q plot for visual inspection of the direction of normality of difference scores.

4 Results

4.1 Examining baseline knowledge of students on sustainability accounting

To answer RQ1, descriptive statistic (Table 2) summarizes the results of the baseline knowledge test performance of the students. The students' mean score for the pre-test was 12.43 (SD = 7.28) out of a possible 30 points. With the scores ranging between 0 and 26 points, most of the students scored below 10 (approx. 45%), while (approx.20%) scored between 11 and 15, bringing the total majority (65%) of the students having a score below the median test value of 15. This suggests a limited baseline knowledge.

However, to ascertain if a significant difference exists between the pre-test mean score and the benchmarked score of 15 (expected average performance), we conducted a

Table 2 Summary of pre and post-test students' scores

Variable pair	Pre-test	Post-test	Difference (Post – Pre)
Test value	15	15	
N	203	203	203
Mean	12.43	18	5.58
SD	7.28	6.25	4.20
Min	0	4	0
Max	26	28	19
SEM	0.51	0.44	0.30
Score above 15	71 (35%)	138 (68%)	
Total scores below 15	132 (65%)	65 (32%)	
Score 11–15	41 (20%)	44 (22%)	
Score below 10	91 (45%)	21 (10%)	
Mean difference (Post - Pre)			5.58
95% CI of the difference			[−6.16, −4.99]
t(df)			−18.91 (202)
Correlation Pre_Test and Post_Test (r)			0.818
p-value			< 0.001
Cohen's d			1.33
Effect size interpretation			Very large
Shapiro-Wilk			0.949, *p*-value < 0.001

one-sample t-test. The result revealed that the students' scores were both significantly different and lower than the test value, indicating the participating students had very limited knowledge of the sustainability accounting concept before the intervention.

This finding aligns with submissions of earlier studies that accounting education, particularly in emerging countries, has been slow to integrate sustainability principles into its curriculum [17, 26, 37]. Aligning with HCT, the knowledge gap highlights the need for focused educational interventions, one that builds relevant competencies for new sustainability-focused practices. This finding justifies the study's focus on leveraging an AI-personalized pedagogy tool to compensate for the shortcomings in traditional teaching approaches.

4.2 Determining the effectiveness of the chatbot intervention tool

To answer RQ2, we ascertained whether the chatbot was instrumental (effective) in enhancing students' knowledge of sustainability accounting using a paired samples t-test to compare the pre-test and post-test scores. i.e., we evaluated students' knowledge before and after interacting with the chatbot. Findings (Table 2) reveal the post-test scores had a mean of 18 (SD = 6.25), significantly higher when compared to the pre-test mean of 12.43 (SD = 7.3). Overall, this yielded an average improvement of 5.58. The effect size, as indicated by Cohen's d = 1.33, was also very large [16], suggesting a great impact of the intervention on the students' learning outcome. This magnitude far exceeds the common thresholds of (0.8) effect size, highlighting the practical significance of the chatbot in enhancing sustainability literacy among undergraduate accounting students in Nigeria. Close examination showed that the majority (68%) of the students after interacting with the chatbot had scores above 15. A strong correlation between the pre- and post-test scores ($r = 0.818$, $p < 0.001$) further reinforces the overall improvement in the students' performance post-intervention. This shows that the students' understanding of the sustainability accounting concept improved greatly after their exposure to the learning intervention. These findings align with those of prior literatures that AI-personalized learning tools fosters deeper understanding and learner engagement outcomes [23, 33, 68]. Hence, it is regarded as an effective pedagogy tool.

Figure 4 visually assesses the spread and direction of the learning impact, revealing the distribution of the difference scores. It showed a slight positive movement (right skewness), suggesting the majority of the students had significant improvement in their performance after engaging with the chatbot.

To enhance the robustness of the result, normality of the difference scores was examined using the Shapiro-Wilk test and Q-Q plot. While the Shapiro-Wilk indicated a significant deviation ($W = 0.949$, $p < 0.001$), visual inspection based on the Q-Q plot (Fig. 5) showed that the data aligned closely to the diagonal line, implying an approximately normal distribution. Therefore, given the large sample size ($N = 203$) of the study and the paired-samples t-test's resilience to small departures from normalcy [28, 31], the normality assumption is assumed met.

The improvement observed in students' learning performance, particularly given the supervised and restricted nature of the chatbot engagement, are attributable to structured exposure to the AI chatbot intervention within this study context. Hence, it is consistent with the CLT view that learners acquire knowledge through hands-on experience, particularly when they actively engage with content, reflect on their experiences, and

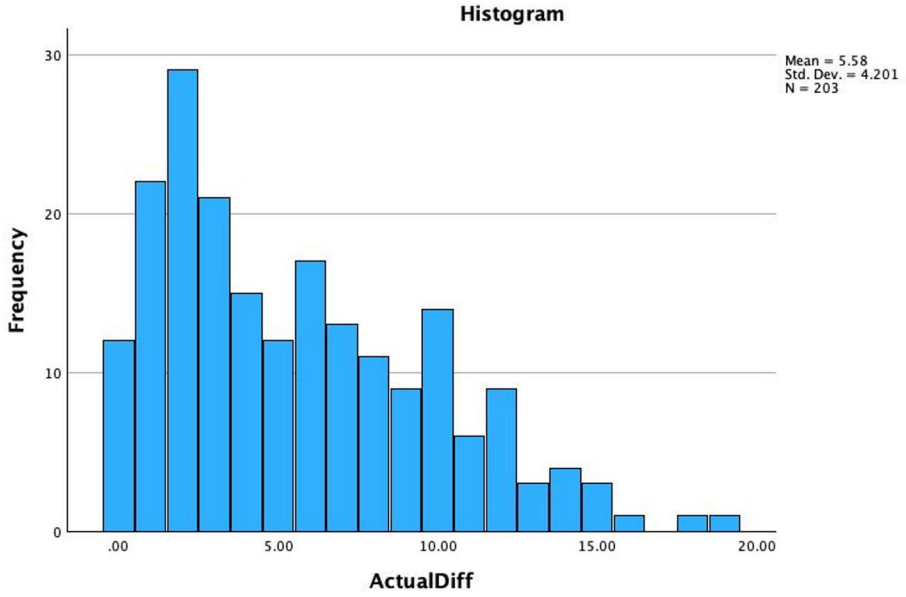


Fig. 4 Histogram representation of the distribution of the difference scores

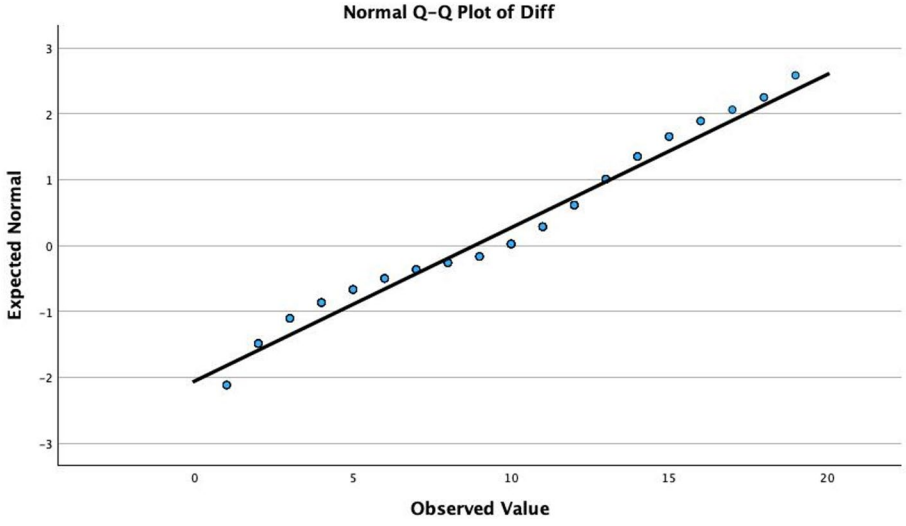


Fig. 5 Q-Q plot of difference scores

apply the knowledge gained in meaningful ways [43, 51]. Hence, given the supervised and restricted nature of the chatbot engagement, the improvements observed at post-test are attributable to structured exposure to the AI chatbot intervention within the study context.Viewing this from the lens of sustainability education, findings reinforce how an AI-personalized pedagogical tool can be leveraged to integrate sustainability-thinking into the core accounting education curriculum, equipping future professionals with the requisite knowledge to address the demands of sustainability concerns [26, 37].

4.3 Evaluation of students' perception of the intervention tool

To answer RQ3 on students' perception of the chatbot as a pedagogical tool for integrating sustainability concepts into accounting education, descriptive statistics were computed across three dimensions, namely: knowledge and skills development,

Table 3 Descriptive summary statistics for students' perceptions of the AI Chatbot

Descriptive summary of estimated marginal means				
Perception dimension	**Overall**	**Active learning (1)**	**Knowledge & skill development (2)**	**Employment and value (3)**
Mean	4.13**	4.05***	4.20***	4.14**
SD	0.74	0.41	0.41	0.40
Cronbach's Alpha	0.88	0.78	0.72	0.75
Std. Error	–	0.047	0.047	0.044
95% CI (Lower- Upper)	–	3.95–4.14	4.11–4.29	4.05–4.23
N	203			

Significant levels: *** 1%; ** 5%; * 10%

employability and professional value, and active learning. Table 3 captures a descriptive summary of all these results.

The test of construct reliability revealed a Cronbach's Alpha value of 0.88 for the overall instrument, indicating the items reliably measure the intended constructs [60]. The subscale reliability coefficients ranged between 0.72 and 0.78, suggesting acceptable internal consistency across dimensions.

Students' responses for all three dimensions were positive and highly significant, with marginal means exceeding 4. Knowledge and skills development had the highest mean of 4.20 (SD = 0.41). Employability and value followed suit with mean 4.14 (SD = 0.40) while active learning had mean 4.05 (SD = 0.41). The 95% confidence intervals for each dimension were well above the scale mid-point, suggesting consistently favourable evaluations of the chatbot intervention.

The overall findings demonstrate that students' view the chatbot as effective in enhancing conceptual understanding and professional preparedness, while also supporting active engagement in learning activities. These results are consistent with prior research in AI-enabled education, which argues that adaptive systems can improve learner outcomes and perceived professional value [4, 5, 68].

These findings reinforce the HCT argument that educational investment holds economic value that increases learners' employability, value, and productivity. Meanwhile, such investment should not be viewed as a mere individual good, but as a strategic tool for enhancing students' knowledge, skills, behaviour, and attitudes, which in the long run will bring economic value to society [12, 54]. In a nutshell, government investments in educational institutions are vital to the country's economic growth because they will foster improved employment prospects by equipping graduates with the skills that employers need. Hence, applying this to education offers a strong foundation for integrating sustainability principles into the accounting curriculum. Chiefly because it equips accounting graduates with the requisite skills that meet the evolving needs of sustainability-driven businesses and global accounting practices.

In addition, in the CLT view, learning can be said to be active, socially mediated, and knowledge-constructed [50, 64]. Despite active learning having the lowest mean of the three dimensions, the findings still reinforce that the chatbot was effective in facilitating interactive and self-directed learning. The lowest mean could be attributed to possible limitations in the chatbot environment's current implementation or students' expectations of more immersive or collaborative experiences. While AI-personalized

pedagogical tools have been found to facilitate conceptual understanding and personalized feedback, previous research indicates that stronger interactions and peer-collaboration features could further improve active learning [2, 3].

Collectively, the results suggests that students perceive the chatbot as an effective and professionally relevant instructional tool for integrating sustainability principles within accounting education.

5 Discussion, conclusion, and limitation

5.1 Discussion

Campaigns to embed sustainability teaching within accounting curricula have intensified lately, alongside recommendations to adopt innovative pedagogies [15, 61]. The findings from this study provide empirical evidence from Nigeria supporting these calls. First, the baseline findings reveal very low prior exposure and knowledge of sustainability accounting concepts among undergraduate students. This finding is consistent with concerns that sustainability information remains unevenly integrated in accounting programs, particularly in developing contexts. The significant post-intervention improvement is suggestive that if a well-structured AI-personalized pedagogical tool is leveraged, it can significantly improve conceptual understanding within a short instructional period. Hence, such a tool can be leveraged to cultivate sustainability-conscious accountants, particularly in environments with limited digital resources like Nigeria.

Specifically, the strongest effect were observed in the knowledge and skills dimension, aligning with prior evidence that the adaptive feedback processes in AI-personalized pedagogy tools enhance self-regulated learning and targeted skills development [65, 67]. Adaptive mechanisms are very crucial within the realm of sustainability accounting because students need to integrate financial reasoning combined with ethical and environmental considerations. Hence, the results suggest that AI-personalized pedagogy tools may effectively strengthen competency-based learning models by bridging theoretical accounting knowledge with applied sustainability reasoning.

Meanwhile, student also reported strong perceptions of employability and professional value, supporting prior findings that digital learning tools are essential to improve students' employability by fostering digital literacy, problem-solving, and analytical reasoning skills often required by employers [19, 24, 45, 58]. Within the context of accounting education, this perception might be reflective of students' awareness of the profession's transformation through ESG disclosure, data analytics, and where competency frameworks are being redefined by emerging cutting-edge technologies. An implication that students increasingly associate sustainability competence and digital literacy with career readiness. Therefore, reinforcing the need to incorporating digital literacy and sustainability competencies into the accounting curriculum [1, 20, 53].

Furthermore, regarding active learning, this dimension showed comparatively lower mean values but still positive. The results align with prior argument that AI-personalized chatbot fosters self-directed learning however may not substitute for social interaction and cognitive reasoning [3]. The finding reinforces the significance of hybrid teaching approaches that combine traditional classroom teaching with AI-personalized form of instruction.

Collectively, the findings indicates that AI-personalized sustainability teaching is pedagogically effective, but most impactful when embedded within broader institutional and collaborative learning structures.

5.2 Policy relevance and institutional implications

The findings from this study are relevant to several stakeholders such as government, NUC, professional accounting bodies, university administrators, and academic staff.

Support from government authorities particularly at the federal ministry of education and state level is foundational to shaping national education policy in terms of digital infrastructural funding and ensuring equitable technology access. Government at relevant levels are therefore urged to support sustainability-oriented accounting education by embedding sustainability and digital competence within the national higher education reform policies, increase access to learning technologies, expand digital infrastructure on campuses, and introduce competitive grants for technology-enabled curriculum innovation in public universities.

The NUC being the apex regulatory body for university education in Nigeria plays the central role in curriculum standardization. Embedding sustainability competencies and digital pedagogy guidance into the Core Curriculum Minimum Academic Standards (CCMAS) would enhance measurable learning outcomes. Hence, NUC can assist to institutionalize these gains across universities.

Professional bodies like the Institute of Chartered Accountants of Nigeria (ICAN) and others can strengthen reform by embedding sustainability accounting and digital literacy into certification requirements, consistent with global expectations advanced by the International Federation of Accountants (IFAC).

Meanwhile, universities and academic staff, in turn, can operationalize these standards through deliberate curriculum redesign with support from Centres for teaching and learning. Interdisciplinary collaboration with computer experts, and adequate digital infrastructure to ensure effective pedagogical implementation.

Collectively, these key actors can foster sustainability-minded accountants by aligning regulatory standards, professional competencies, institutional investment, and classroom practice.

5.3 Conclusion, contribution, limitations and future research agenda

This study provides empirical evidence that AI-powered personalized chatbots can considerably enhance sustainability accounting literacy and strengthen perceived readiness among undergraduate accounting students in Nigeria. Employing CLT and HCT, the pre–post knowledge gains demonstrate how structured technology-based teaching can effectively address gaps in sustainability literacy within accounting curricula. This study therefore contributes to on-going discourse on sustainability accounting, AI in accounting pedagogy, and digital innovation in emerging climes. Most importantly, it offers contextual evidence from an environment where infrastructural constraints often hinder pedagogical innovation and adoption.

Beyond its pedagogical value, the findings align with broader sustainability development initiatives. By demonstrating that technology-enabled instructional models can improve measurable learning outcomes and promote competency-based education, the chatbot intervention enhanced not only conceptual understanding but also self-regulated

learning and applied reasoning, which are central to inclusive and effective higher education. This aligns with SDG 4 on (Quality education). Furthermore, the integration of AI into accounting education reflects the evolving digital transformation of the profession, particularly in ESG analytics, sustainability reporting, and technology-driven financial systems. By fostering digital literacy combined with sustainability competence, the intervention contributes to building innovation-oriented human capital capable of supporting evolving industry demands under SDG 9 (industry, innovation, and infrastructure). Finally, advancing sustainability-oriented accounting education cannot be achieved by the universities alone. Concerted efforts and action are required among government authorities, regulatory agencies, professional bodies, and higher education institutions, underscoring the relevance of SDG 17 (partnerships for the goals).

Despite the study contributions, it is limited in several ways that may offer direction for future research. First, the study was conducted under a supervised and controlled classroom conditions, its lack of a counterfactual comparison group still constrains the extent to which alternative threats to internal validity can be definitively ruled out; hence, causal interpretation of the intervention effect remains cautiously bounded. Findings thus only offer preliminary evidence of the chatbot's instructional effectiveness within the study context. Future research should employ quasi-experimental or randomized controlled designs with matched comparison groups as this might further strengthen causal attribution and isolate chatbot-specific effects. Second, the time interval and absence of feedback employed as a control measure may have reduced immediate recall bias. But the study design may not have fully eliminate the possibility of item structure familiarity from influencing score improvement. Future research should consider parallel test forms to account for practice effect. Third, the study relied on perception data and performance measures, but detailed usage analytics were not captured. Subsequent research could investigate engagement intensity, learning trajectories, and subgroup differences using interaction-level data. Fourth, cross-country and cross-institutional studies can enhance generalizability and reveal how regulatory environments moderate effectiveness of chatbot. Fifth, the intervention focused on individualized chatbot learning. Comparative studies examining hybrid models that combine AI tools with collaborative classroom activities can clarify optimal instructional design.

In a nutshell, while AI-enabled sustainability teaching may be a viable strategy for enhancing accounting education in Nigeria, its long-term impact, however, is contingent on coordinated action by regulators, professional groups, university leadership, and academic staff to establish sustainability and digital competency as essential pillars of accounting education.

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Author contributions
NG : writing—original draft, conceptualization, instrument development, methodology, writing—review and editing, hypothesis development, data curation, data analysis. AA : conceptualization, software development, writing—review and editing. SO: software development, methodology, conceptualization, writing— review and editing.

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Data availability
The datasets employed for this research will be made available by the authors upon reasonable request.

Declarations

Ethics approval and consent to participate
The research project was approved by the Johannesburg Business School Research Ethics Committee (JBSREC) in accordance with the guidelines provided by the University of Johannesburg. The ethical clearance with code JBSREC202438 was granted. The study which was conducted following the approval of the Johannesburg Business School Research Ethics Committee (JBSREC) is in accordance with the guidelines stipulated in the "University of Johannesburg Code of Academic Ethics and Research Ethics" now "University of Johannesburg Policy on Research Integrity". Informed consent was obtained from all respondents engaged in this research and they were assured of their anonymity.

Consent for publication
All authors have reviewed and approved this manuscript for publication.

Competing interests
The authors declare no competing interests.

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