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Enhancing entrepreneurial skills through experiential learning in IoT, AI, and cybersecurity

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Abstract
The integration of Internet of Things (IoT), Artificial Intelligence (AI), and cybersecurity presents new opportunities for innovation and entrepreneurship, yet traditional educational approaches often lack the interdisciplinary and applied focus required to develop these competencies. This study evaluates the impact of an experiential learning workshop that integrated IoT prototyping, AI-based anomaly detection, and cybersecurity principles to promote technical understanding, entrepreneurial thinking, and ethical awareness. Conducted at Godfrey Okoye University, Nigeria, the workshop engaged 476 undergraduate students from diverse academic disciplines in project-based learning activities and collaborative design challenges. Statistical analysis of matched pre- and post-assessments revealed a mean increase of 25.5 percentage points (95% confidence intervals $\pm 4.2\%$, $p < 0.001$) in quiz performance across all three domains. Regression and exploratory mediation analysis indicated that prior knowledge and engagement with hands-on tasks were significant predictors of learning gains. Qualitative feedback highlighted the perceived value of real-world application, teamwork, and ethical reflection. The findings demonstrate the efficacy of experiential and interdisciplinary educational models in fostering future-ready skills and responsible innovation. This study offers actionable guidance for designing inclusive, scalable technology learning interventions and contributes to advancing Sustainable Development Goal 4 on equitable quality education.

Keywords Experiential learning · Technology education · Internet of things · Artificial intelligence · Cybersecurity · Entrepreneurship

1 Introduction

The rapid advancement of emerging technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), and cybersecurity, is reshaping industries and creating unprecedented opportunities for innovation. IoT facilitates the interconnection of physical devices, which enables seamless data exchange across platforms and applications [2]. When integrated with AI, which processes and analyzes the vast data collected by IoT, these technologies enhance decision-making, operational efficiency, and predictive capabilities [37]. The combined power of IoT and AI has led to innovations in diverse sectors such as healthcare, smart cities, and agriculture. For example, AI-driven IoT solutions have enabled predictive maintenance in industrial settings, reducing downtime and optimizing resource utilization [19]. Similarly, smart

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agriculture systems equipped with IoT sensors and AI algorithms enhance crop management and water conservation [31, 44]. These examples underscore the potential of IoT and AI to solve real-world problems while fostering entrepreneurship.

However, the growing adoption of these technologies also amplifies cybersecurity challenges. IoT devices, often designed with limited computational resources, are particularly susceptible to security vulnerabilities, which makes them prime targets for cyberattacks [9]. Moreover, the increasing reliance on AI introduces risks such as adversarial attacks, where malicious actors manipulate AI systems to produce incorrect outputs [37]. Addressing these challenges is critical for ensuring the confidentiality, integrity, and availability of systems [33]; which are the cornerstones of cybersecurity.

While theoretical knowledge provides the foundation for understanding emerging technologies, constructivist learning theory highlights that practical, hands-on experience is essential for meaningful knowledge construction. Experiential learning, as framed by Kolb [24], promotes learning through action, reflection, and application in real-world contexts, which are approaches that are particularly well-suited to the complexity of technology education. Practical workshops serve as a bridge between theory and practice, offering participants the opportunity to prototype, troubleshoot, and iterate under guided supervision [6]. In the context of cybersecurity, IoT, and AI, such workshops enable learners to build and test systems, analyze data, and implement protection strategies. These learning experiences foster critical thinking, creativity, technical confidence, and real-world readiness [13].

This study investigates the effectiveness of an interdisciplinary, experiential workshop designed to integrate IoT, AI, and cybersecurity concepts for aspiring entrepreneurs. Conducted at Godfrey Okoye University, Nigeria, the workshop provided 476 participants from diverse academic backgrounds with applied learning experiences focused on solving real-world challenges using these technologies. Through hands-on activities, collaborative exercises, and structured discussions on responsible innovation, the program aimed to cultivate technical competence, entrepreneurial thinking, and ethical awareness.

The workshop aligns with recent calls in educational research for interdisciplinary, constructivist, and project-based learning models, particularly in the context of technology and entrepreneurship education [7, 14, 41, 46]. It also responds to the need for scalable and accessible models by leveraging low-cost tools such as Arduino and Google Colab, which facilitate inclusive participation in resource-constrained environments.

Accordingly, this study evaluates the workshop's effectiveness through a mixed-methods approach [11], combining pre- and post-intervention assessments with qualitative feedback from participants. The findings indicate statistically significant improvements in students' knowledge of IoT, AI, and cybersecurity, alongside increased confidence and a deeper appreciation of these technologies' ethical and entrepreneurial dimensions. By presenting an adaptable model for experiential technology education, this study contributes to the growing discourse on preparing students for digitally driven futures.

The remainder of this paper is structured as follows. Section 2 contextualizes the study within existing research on experiential and entrepreneurial education. Section 3 details the workshop design, participants, procedure, and data collection and analysis methods. Section 4 presents the quantitative and qualitative findings, while Section 5 interprets these results in light of existing literature and offers actionable implications as well as limitations of the study and future directions. Section 6 concludes the paper by emphasizing the value of integrated, experiential learning models in technology education.

2 Literature review

This section reviews existing literature on experiential learning, interdisciplinary approaches in technology education, and entrepreneurial pedagogy to contextualize the workshop's design and objectives.

2.1 Experiential learning in technology education

Experiential learning is a dynamic pedagogical approach grounded in constructivist theory, where learners actively construct knowledge through real-world engagement, reflection, and application. One of the most influential models in this domain is Kolb's [24] experiential learning theory, which conceptualizes learning as a cyclical process involving four key stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. This model has proven especially effective in technology education, where the translation of abstract concepts into functional understanding often requires hands-on interaction with tools and systems.

Numerous studies have demonstrated that experiential learning enhances knowledge retention, problem-solving ability, and learner engagement when compared to traditional lecture-based approaches. For example, Biggs et al. [6] found that students who engage in practical activities, such as prototyping or simulations; are better equipped to transform theoretical concepts into actionable skills. In the context of IoT education, exercises like programming microcontrollers or configuring sensor networks enable learners to understand how physical systems operate, communicate, and respond within integrated environments [1].

Beyond reinforcing conceptual knowledge, experiential learning fosters creativity and critical thinking by encouraging students to experiment, iterate, and respond to open-ended challenges. Fantinelli et al. [13] observed that structured practical experiences within technology-focused curricula significantly enhanced learners' adaptability and career readiness, which are key competencies for the demands of evolving digital economies.

Moreover, experiential learning promotes learner engagement and motivation, which are critical in technology education [34, 36]. Interactive and collaborative activities, such as group projects and case studies, allow students to apply their knowledge in meaningful ways, enhancing their sense of ownership and responsibility for their learning outcomes [17, 26, 48, 49]. This approach aligns with modern pedagogical frameworks that prioritize active learning as a means of fostering student agency and autonomy.

Despite its benefits, the implementation of experiential methods in technology education is not without challenges. Effective delivery often depends on access to specialized equipment, software, and technical expertise, which are resources that are not uniformly available, especially in resource-constrained settings [16, 23, 35]. Yet, recent innovations in educational technology have helped lower these barriers. The use of open-source platforms and affordable tools, such as Arduino for IoT or Google Colab for AI programming, has enabled scalable and inclusive experiential learning opportunities across diverse educational contexts.

2.2 Interdisciplinary learning in IoT, AI, and cybersecurity

The interconnected nature of IoT, AI, and cybersecurity necessitates an interdisciplinary approach to education. Individually, these fields have transformative potential; collectively, they create robust solutions to complex challenges, such as enhancing healthcare delivery, optimizing resource management, and securing critical infrastructure. However, traditional education often treats these domains in isolation, neglecting the synergies that arise when they are integrated into a cohesive learning framework [51].

Also, IoT systems rely heavily on AI for real-time data analysis and decision-making [37]. For instance, AI algorithms can process vast amounts of data collected from IoT sensors to detect anomalies, predict trends, and automate responses. Simultaneously, cybersecurity ensures the confidentiality, integrity, and availability [33] of these interconnected systems, safeguarding them against malicious attacks and data breaches. Educating students about the interplay of these fields equips them with the ability to design holistic solutions that address technical, operational, and ethical challenges.

A growing body of research supports the value of interdisciplinary education in preparing students for the demands of modern technology ecosystems. Tariq [52] argued that integrating multiple disciplines fosters creativity and innovation by encouraging learners to think beyond traditional boundaries. In the context of IoT, AI, and cybersecurity, interdisciplinary education enables students to approach problems holistically, considering how these technologies interact and influence one another.

Practical examples of interdisciplinary education further illustrate its benefits. Tafa et al. [51] described a new course dedicated to capability maturity model integration-directed design of wireless sensor networks-based biomedical applications that stresses engineering, medico-engineering, and informatics-related issues. The course not only improved students' technical skills but also encouraged them to consider broader societal implications, such as the creation of synergy that enables interdisciplinary teams to organize and develop health-related pervasive computing applications. Similarly, cybersecurity education that integrates IoT and AI enables students to address vulnerabilities specific to connected devices and machine learning systems.

Another key strength of interdisciplinary education is its ability to prepare students for collaborative, cross-functional roles in technology-driven industries [5, 40, 51]. By exposing learners to multiple fields, interdisciplinary education equips them with the flexibility and adaptability needed to navigate dynamic and interconnected work environments. This is particularly important as industries increasingly seek professionals who can bridge the gaps between technical expertise, operational efficiency, and ethical responsibility.

However, implementing interdisciplinary education presents challenges, particularly in resource-constrained settings [47, 54]. Designing curricula that integrate multiple disciplines requires collaboration among educators with diverse expertise, as well as access to relevant tools and technologies. To address these challenges, educational institutions can leverage open-source platforms, foster partnerships with industry, and promote professional development programs for faculty.

2.3 Entrepreneurial education and technology workshops

Entrepreneurial education plays a critical role in equipping students with the skills and mindset needed to identify opportunities, develop innovative solutions, and create value in dynamic and uncertain environments [12, 38, 43, 45]. This is particularly relevant in technology-driven fields such as IoT, AI, and cybersecurity, where innovation often requires a combination of technical expertise and entrepreneurial thinking [15, 28, 55]. Experiential workshops have also emerged as a powerful tool in this domain [39, 50, 56]. They offer students the opportunity to apply theoretical knowledge in practical, entrepreneurial contexts.

Grounded in constructivist and experiential learning theory, entrepreneurial education emphasizes learning through action, experimentation, and reflection [32]. Rather than relying solely on lectures or case studies, this approach encourages students to engage in real-world problem solving, often through project-based activities that simulate entrepreneurial processes. Activities such as ideation, prototyping, pitching, and market validation not only reinforce core concepts but also foster creativity, collaboration, and adaptability, which are key attributes for future innovators.

In recent years, integrating entrepreneurship into technology education has gained increasing attention as a means to promote student agency, applied learning, and innovation. Workshops that combine technical learning with entrepreneurial design challenges offer students the chance to build solutions that are both technologically feasible and socially relevant. For example, Crabb et al. [10] described a workshop that blended, field trips, lectures, and interactive learning experiences to equip students from diverse backgrounds with cybersecurity skills and career insights. This type of initiative not only enhanced participants' technical capabilities but also their professional skills.

Despite their benefits, implementing entrepreneurial workshops in technology education requires careful planning and resource allocation [25, 30]. Educators must design activities that balance technical rigor with creativity and practical application. Additionally, support from policymakers and institutions is critical for providing the necessary resources, such as access to tools, mentorship, and funding [8, 27]. Collaboration with industry partners can further enhance the impact of these workshops by offering participants real-world insights and opportunities for professional growth.

2.4 Research gaps

While existing research has significantly advanced our understanding of experiential and interdisciplinary education, several gaps remain, particularly in the context of integrating IoT, AI, and cybersecurity within entrepreneurial learning frameworks. Addressing these gaps is essential for refining educational models and ensuring their relevance in preparing students for the demands of modern technological and entrepreneurial ecosystems.

A primary gap lies in the limited educational research that addresses the integration of IoT, AI, and cybersecurity within a single, cohesive learning program. These domains are often taught independently, despite their increasing interdependence in real-world applications. For instance, AI is used to process data collected by IoT systems, while cybersecurity is essential for protecting the integrity of both [37]. Fragmented instruction risks overlooking the systemic thinking required to design, secure, and optimize such integrated systems. This study contributes to filling this gap by demonstrating how interdisciplinary, project-based learning can foster both conceptual integration and applied skill development.

While the value of experiential learning for skill development is well established [6, 24], less attention has been paid to its role in cultivating entrepreneurial mindsets, especially in resource-constrained settings. In emerging economies, hands-on innovation experiences may play a critical role in inspiring students to develop locally grounded solutions. The workshop evaluated here provides preliminary insights into how experiential learning can empower learners to identify community-specific challenges, such as in agriculture and healthcare; and explore entrepreneurial applications of emerging technologies.

As technologies like AI and IoT become more embedded in daily life, ethical dilemmas such as data misuse, algorithmic bias, and system vulnerability are becoming increasingly relevant. Yet, many educational models either treat ethics as an adjunct topic or omit it entirely from technical curricula [20, 21, 29]. There is a need for research on how to effectively embed ethical reflection and responsibility into technical learning experiences. By incorporating discussions of responsible innovation into its activities, the workshop featured in this study illustrates one pathway for addressing this pedagogical need.

Additionally, much of the literature emphasizes individual learning outcomes, such as cognitive gains or self-efficacy; with less focus on how collaborative, team-based experiences contribute to innovation readiness. However, real-world entrepreneurship and technology development are inherently collaborative, requiring cross-disciplinary teamwork and co-creation. This study addresses this gap by embedding structured group tasks such as collaborative prototyping and brainstorming, aligned with real-world innovation processes.

Lastly, while experiential learning is increasingly promoted, questions remain about its scalability and cultural adaptability; especially in under-resourced environments. Many existing studies are conducted in resource-rich environments, making it unclear how such models translate to more constrained educational settings. This study contributes by demonstrating the feasibility of using affordable, open-source tools (e.g., Arduino, Google Colab) to deliver meaningful learning experiences. Still, further research is needed to evaluate how experiential learning frameworks can be tailored to different institutional and cultural contexts.

3 Methodology

This section outlines the design, implementation, and evaluation of the experiential workshop conducted at Godfrey Okoye University, Enugu, Nigeria. The methodology is presented in five subsections: workshop design, participants, procedure, data collection and analysis, and ethical considerations.

3.1 Workshop design

The workshop was conceptualized as a one-time, immersive educational intervention for undergraduate students with a strong interest in technology and entrepreneurship. Its primary aim was to provide a unified, interdisciplinary learning experience that integrated IoT, AI, and cybersecurity. The workshop's pedagogical foundation was grounded in Kolb's [24] experiential learning theory, which emphasizes learning through a four-stage cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation. By aligning its structure with this framework, the workshop sought to deepen technical understanding, foster entrepreneurial thinking, and promote ethical engagement with emerging technologies.

The workshop began with an Introduction to IoT, AI, and Cybersecurity, which established a foundational understanding of each domain. This session explored the individual characteristics of IoT, AI, and cybersecurity and their interconnected roles in addressing real-world problems. For example, IoT systems often rely on AI for data-driven decision-making, while cybersecurity ensures the safety and reliability of these interconnected systems. Research supports this thematic integration, noting that interdisciplinary instruction fosters deeper understanding and prepares students to address complex challenges [14, 41].

Following the introductory sessions, participants engaged in a series of hands-on activities designed to reinforce theoretical knowledge through practical application. Activities included using Google Colab to demonstrate AI-based anomaly detection and learning how machine learning algorithms process sensor data to identify irregularities and cybersecurity exercises. These practical exercises align with Kolb's [24] experiential learning theory, which emphasizes the importance of active experimentation and reflection in solidifying learning. They also reflect the findings of Jabarullah and Iqbal Hussain [22], who highlighted the value of hands-on activities in enhancing students' technical proficiency and problem-solving skills.

to further support interdisciplinary learning, participants worked in diverse groups to identify local challenges and develop technology-driven solutions. For instance, some groups proposed IoT-enabled health monitoring systems for rural areas, while others focused on AI-powered tools for optimizing water usage in agriculture. These collaborative exercises encouraged teamwork, creativity, and peer learning, reflecting the real-world demands of interdisciplinary innovation. Research shows that group-based activities enhance student engagement and promote the development of communication and collaboration skills critical for entrepreneurial success [4].

The final segment of the workshop involved pitch development, where groups shared their proposed solutions. This activity mirrored the four-stage iterative entrepreneurial process of ideation, prototyping, market engagement, and business modeling, as described by Goldsby et al. [18], and provided participants with practical experience in articulating and defending their ideas. Ethical dimensions were integrated into each segment, particularly through discussions on data privacy, algorithmic bias, and cybersecurity best practices. This embedded approach helped students critically reflect on how emerging technologies can be deployed responsibly.

Importantly, the workshop was designed with accessibility in mind. Tools like Arduino and Google Colab were selected for their affordability and low barrier to entry, making it possible for students from diverse academic and socio-economic backgrounds to participate meaningfully. While the workshop was a one-time event, its structure aimed to maximize learning impact by combining experiential engagement, collaborative innovation, and ethical reflection within an interdisciplinary context.

3.2 Participants

Participation in the workshop was voluntary and open to all students at Godfrey Okoye University, regardless of academic discipline or level of study. The open invitation was disseminated across departments and student networks, ensuring broad access and inclusivity. A total of 476 students attended the workshop, with 301 participants completing the pre-workshop survey, yielding a 63.2% initial response rate. Participants ranged in age from 16 to 23 years, with the most common age being 19 years (n = 58, 19%).

In terms of gender distribution, the participant group comprised 235 males (78%), 62 females (21%), and 4 individuals (1%) who preferred not to disclose their gender. While the gender disparity reflects broader patterns of underrepresentation in science, technology, engineering, and mathematics (STEM) fields, especially in certain regions, it also highlights the need for targeted outreach and support mechanisms to foster greater gender equity in technology-focused programs. Future iterations of the workshop will explore strategies to actively encourage more inclusive participation.

The workshop also drew participants from diverse academic backgrounds and levels. Approximately 31% (n = 92) of survey respondents identified as undergraduate students, while others reported affiliations with secondary education, diploma programs, or graduate-level coursework. This variation reflects the open-access nature of the event and underscores its appeal across a wide range of learners.

Regarding assessment participation, 216 students completed the pre-workshop quiz, while 112 completed the post-workshop quiz. Similarly, 101 participants completed the post-workshop survey, reflecting a natural attrition rate commonly observed in voluntary educational interventions. This drop-off is acknowledged as a limitation and is addressed further in the analysis and discussion sections.

Throughout the workshop, participants demonstrated high levels of engagement. Anecdotal observations and feedback indicate that students were actively involved in brainstorming sessions, hands-on technical activities, and collaborative group discussions. The diversity of academic backgrounds also enriched the learning experience, as interdisciplinary teams enabled peer learning and fostered creative thinking. Several students expressed appreciation for the opportunity to engage with peers from other disciplines, highlighting the value of collaborative innovation in technology education.

3.3 Procedure

The workshop followed a structured sequence designed to assess participants' baseline knowledge, deliver targeted experiential learning activities, and evaluate post-workshop outcomes. Given the diverse academic backgrounds and varying levels of prior exposure to IoT, AI, and cybersecurity, it was essential to first establish participants' familiarity and learning needs.

To this end, participants were invited to complete a pre-workshop survey, which collected demographic data, such as age, gender, and academic affiliation; as well as self-reported familiarity with the core technology domains addressed in the workshop. This information helped facilitators tailor content delivery strategies and gauge inclusivity across disciplines. In addition to the survey, participants were administered a pre-quiz comprising multiple-choice questions designed to objectively assess their baseline understanding of key concepts in IoT, AI, and cybersecurity.

Following the learning activities, participants were asked to complete a post-quiz that mirrored the structure and content areas of the pre-quiz. This allowed for a direct comparison of knowledge gains. Alongside the quiz, a post-workshop survey was distributed to capture students' perceptions of the workshop's quality, relevance, and impact on their technical skills and entrepreneurial thinking. The survey also included open-ended items that enabled participants to reflect on their learning experiences and suggest improvements for future iterations.

To enhance engagement and create opportunities for reflection and feedback during the sessions, the workshop also incorporated the use of interactive digital tools, most notably Mentimeter. This platform was employed for real-time polling, short knowledge checks, and group brainstorming exercises. These interactive moments served both pedagogical and evaluative functions, which helped facilitators adjust pacing and content in response to participant feedback, while also encouraging learners to actively contribute and share their insights.

Throughout the workshop, facilitators maintained a learner-centered approach consistent with experiential and constructivist learning principles. The structured combination of surveys, quizzes, and interactive engagement tools provided a rich, multi-modal data set for evaluating the workshop's effectiveness and informed the mixed-methods analysis described in the next section.

3.4 Data collection and analysis

Data were collected through a combination of pre- and post-workshop quizzes, structured surveys, and real-time interactive feedback using Mentimeter. These instruments were selected to capture both quantitative and qualitative data, supporting a mixed-methods approach consistent with the study's experiential and constructivist orientation. This design enabled the triangulation of participant responses, which helped to validate findings and offer a multidimensional understanding of the workshop's effectiveness.

For the quantitative component, all participants were invited to complete a quiz assessing their knowledge of IoT, AI, and cybersecurity prior to the workshop and a quiz administered at the end of the session. Each quiz contained multiple-choice items aimed at measuring both conceptual understanding and applied knowledge. In addition to knowledge scores, data on student engagement, which were measured through activity participation logs, including brainstorming sessions and pitch development exercise; were recorded to explore their relationship with learning outcomes.

The analysis of quiz data began with paired-sample t-tests to determine whether post-workshop scores differed significantly from pre-workshop scores. These analyses provided insight into the overall effectiveness of the workshop in improving technical knowledge. To further examine the influence of various factors on learning outcomes, a multiple regression analysis was conducted, using post-quiz scores as the dependent variable and pre-quiz scores, engagement levels, and self-reported interest in technology as predictors.

In order to explore causal mechanisms within the learning process, mediation analysis was performed using bootstrapping techniques. Specifically, the model tested whether engagement in hands-on activities functioned as a mediator between baseline knowledge and post-workshop performance. While the mediation analysis offered exploratory insights into the role of engagement, its application in a single-timepoint intervention is theoretically limited. Future studies should incorporate a robust theoretical framework and a multi-timepoint design to strengthen causal claims. Additionally, Pearson correlation coefficients were calculated to examine relationships between engagement, satisfaction, and knowledge gains. All statistical analyses were conducted using Python-based packages (statsmodels and scikit-learn), with an alpha level of 0.05 used to determine statistical significance. Model assumptions, such as normality, linearity, and multicollinearity; were tested using standard diagnostics including residual plots and variance inflation factors.

The qualitative component of the analysis drew on data from the post-workshop surveys, which included open-ended questions that captured participants' reflections on the workshop's relevance, effectiveness, and areas for improvement. In addition, real-time responses collected through Mentimeter provided immediate insights into student perceptions of specific activities. These responses were coded thematically using an inductive approach to identify patterns in learner experiences and perceptions.

To ensure reliability and validity, all quiz and survey instruments were reviewed by three subject matter experts. The internal consistency of the quiz instrument was assessed using Cronbach's alpha, which yielded a coefficient of 0.87. However, given that the quiz spanned distinct subject areas, we acknowledge that this measure may overstate homogeneity. We have therefore interpreted the reliability measure cautiously and used domain-specific analyses to supplement it by ensuring that item difficulty and structure were balanced. Triangulation of data from quizzes, surveys, and interactive tools further enhanced the validity of the findings by providing a comprehensive picture of learning outcomes and participant experiences.

Taken together, this analytical approach allowed the study to capture both measurable learning gains and subjective participant insights, offering a nuanced evaluation of the workshop's impact on interdisciplinary learning, entrepreneurial awareness, and ethical reflection.

3.5 Ethical considerations

The study was conducted in accordance with the Guidelines for Research Ethics in the Social Sciences and the Humanities [53]. Participants were informed about the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any time without penalty. Consent was obtained prior to data collection, with assurances of confidentiality and anonymity provided. No health or personal data were collected in the survey. Moreover, the Godfrey Okoye University Research Committee confirmed that no additional ethical approval was required for this research.

4 Results

This section presents the findings of the study, organized into two subsections: quantitative results, which include descriptive statistics and inferential statistics, and qualitative results, which provide insights into participants' perceptions and experiences during the workshop.

4.1 Quantitative results

4.1.1 Descriptive statistics

Descriptive analyses of quiz scores, engagement levels, and satisfaction ratings provide an overview of the workshop's impact on participants' learning and experience. These data were derived from pre- and post-workshop assessments, surveys, and interactive activities facilitated during the event.

The pre-workshop quiz results indicated moderate baseline knowledge across the three technology domains, with mean scores of 52% for IoT, 55% for AI, and 56% for cybersecurity. Following the workshop, mean scores increased significantly to 78%, 80%, and 82% respectively; representing average gains of 25–26 percentage points. These improvements are visualized in Figure 1, which depicts side-by-side comparisons of pre- and post-assessment performance, confirming marked knowledge acquisition in all thematic areas.

In terms of engagement, participation rates in various interactive components were high. Over 45% of students engaged in real-time polls using Mentimeter, which offered opportunities to reflect on content and contribute to collective feedback. Approximately 70% of participant groups contributed solutions during brainstorming sessions, while 63% participated in pitch development exercises. These activities were instrumental in encouraging teamwork, creativity, and practical application of theoretical concepts.

Results from the post-workshop survey indicated strong satisfaction among participants. A substantial majority (95%) found the workshop content relevant to their academic or entrepreneurial interests. Furthermore, 92% of respondents identified the hands-on exercises as the most valuable component of the workshop. Notably, 88% expressed increased confidence in applying IoT, AI, and cybersecurity concepts to solve real-world problems. These findings highlight not

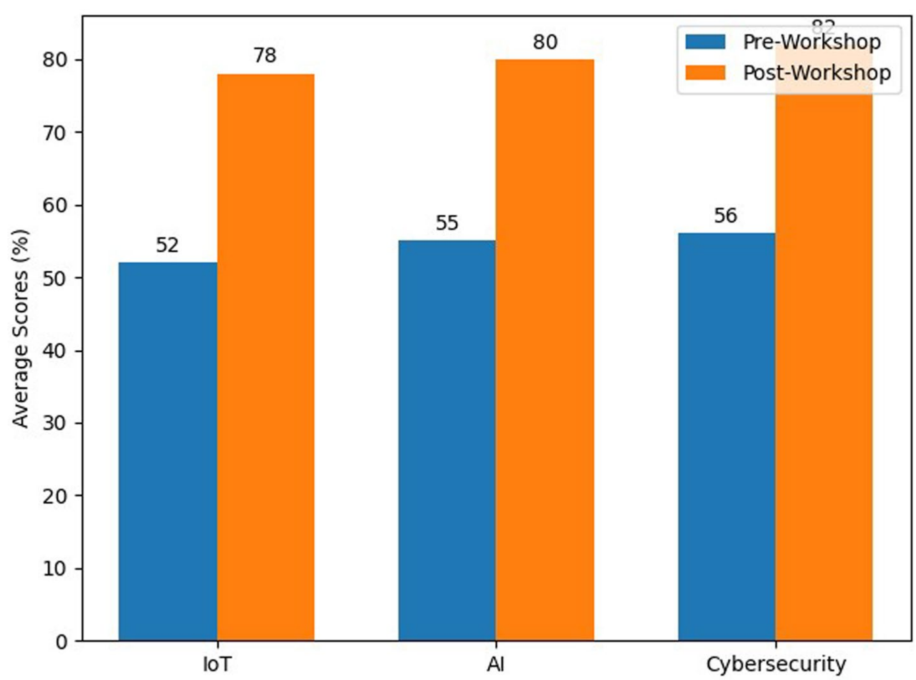

Fig. 1 Pre- and post-quiz scores by theme

Table 1 Paired T-test results for pre- and post-quiz scores

Metric	IoT	AI	Cybersecurity
Pre-Quiz Mean (%)	52	55	56
Post-Quiz Mean (%)	78	80	82
Mean Difference (%)	+26	+25	+26
t-Statistic	-18.45	-17.83	-19.21
p-Value	< 0.001	< 0.001	< 0.001

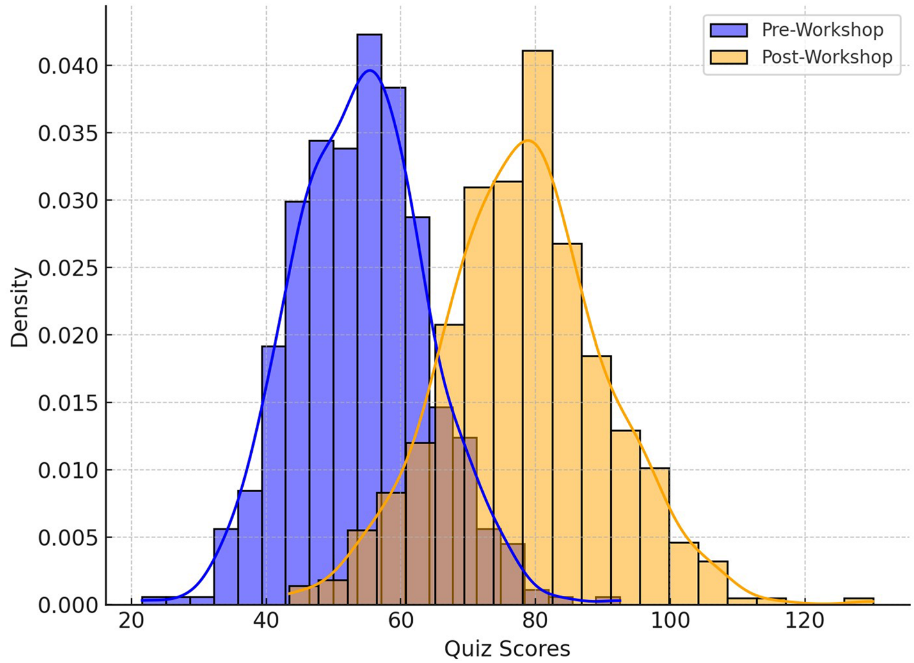

Fig. 2 Pre- and post-quiz score distribution

only improvements in technical understanding but also increased self-efficacy and entrepreneurial motivation among participants.

4.1.2 Inferential statistics

To evaluate the workshop's effectiveness comprehensively, inferential statistical analyses were conducted on the data collected from pre- and post-workshop quizzes, surveys, and engagement metrics. These analyses included paired t-tests, multiple regression, mediation, and correlation analyses, providing robust insights into the relationships between workshop components and participants' learning outcomes.

A paired t-test was conducted to compare participants' pre- and post-workshop quiz scores, focusing on IoT, AI, and cybersecurity domains. The results indicated statistically significant improvements in scores across all areas, highlighting the workshop's effectiveness in enhancing participants' understanding of these key technologies. On average, pre-quiz scores were 54.3% (SD = 12.5), increasing to 78.6% (SD = 10.2) post-workshop. The specific results for each domain are detailed in Table 1. The distribution of quiz scores is visualized in Figure 2, which compares pre- and post-workshop scores. The density plot shows a clear rightward shift in the post-workshop scores, indicating significant knowledge gains. The clustering of post-workshop scores around higher percentages reflects the participants' improved understanding of IoT, AI, and cybersecurity concepts.

To explore the predictors of learning outcomes, a multiple regression analysis was conducted using post-quiz scores as the dependent variable. The model explained 58.5% of the variance in post-quiz scores ($F(2, 497) = 350.2, p < 0.001$). Pre-quiz scores emerged as the strongest predictor, with a coefficient of $\beta = 0.943, p < 0.001$, suggesting that participants with higher baseline knowledge experienced greater learning

Table 2 Regression Analysis Summary

Predictor	Coefficient (β)	p-value
Constant	17.81	< 0.005
Post-Quiz Scores	0.943	< 0.001
Engagement	0.111	0.108

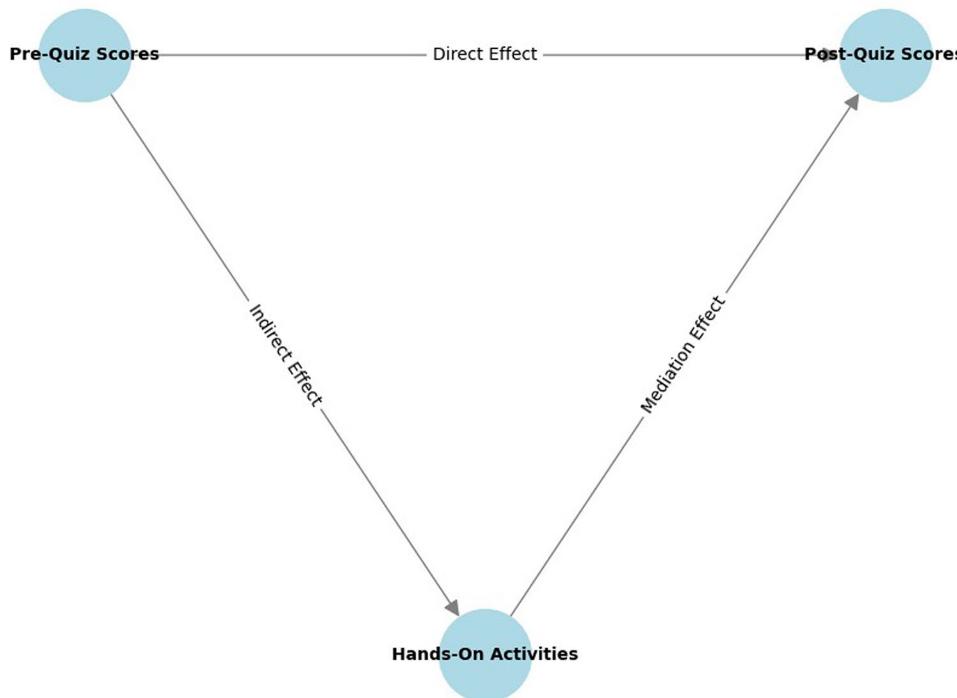

Fig. 3 Mediation analysis model

gains. Engagement levels were positivley associated with post-quiz performance ($\beta = 0.111$) but did not reach statistical significance ($p = 0.108$). The results are summarized in Table 2.

To examine the mechanisms underlying the observed learning gains, a mediation analysis was performed using bootstrapping techniques. The analysis investigated whether engagement in hands-on activities mediated the relationship between pre- and post-quiz scores. Results showed a significant indirect effect of $\beta = 0.18, p < 0.01$, accounting for approximately 40% of the total effect, indicating that active participation in experiential components partially explained the gains in knowledge. Figure 3 illustrates this mediation model, depicting both direct and indirect pathways between the variables.

A final correlation analysis assessed the relationships between key variables: engagement, post-quiz performance, and participant satisfaction. Engagement levels were positively correlated with post-quiz scores ($r = 0.42, p < 0.001$) and participant satisfaction ($r = 0.38, p < 0.001$). Additionally, post-quiz scores showed a strong positive correlation with satisfaction ratings ($r = 0.86, p < 0.001$), suggesting that improved knowledge strongly influenced participants' perceptions of the workshop's effectiveness. Figure 4 shows the strong positive correlation between post-quiz scores and satisfaction ratings. The trend line reflects the consistent relationship, highlighting how improved knowledge contributed to participants' positive perceptions of the workshop.

Together, these analyses offer robust evidence that the workshop was effective in advancing participants' technical understanding, particularly when baseline knowledge was high and engagement in hands-on activities was strong. The findings also underscore the importance of designing learning environments that combine interactivity, practical application, and learner agency to maximize educational impact.

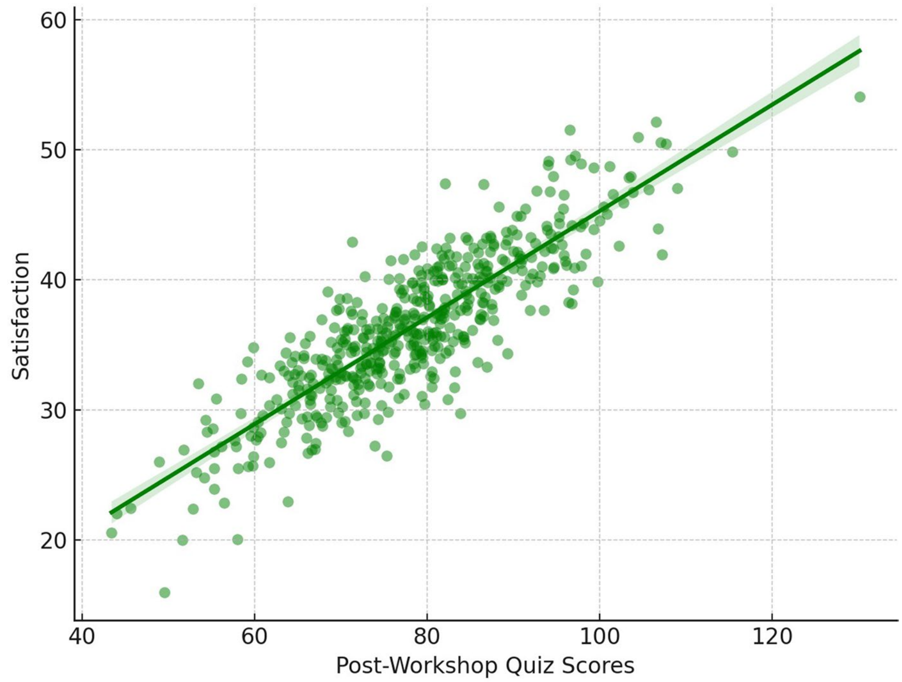

Fig. 4 Correlation between post-quiz scores and satisfaction ratings

4.2 Qualitative results

The qualitative analysis provided rich insights into participants' experiences during the workshop, highlighting key themes such as content relevance, the impact of hands-on activities, collaborative learning, ethical awareness, and suggestions for improvement. These findings complement the quantitative results by capturing the participants' perceptions and reflections.

4.2.1 Content relevance and practicality

Participants consistently emphasized the relevance and practicality of the workshop content. The integration of IoT, AI, and cybersecurity resonated with their academic and entrepreneurial interests, particularly in addressing real-world challenges. Many participants noted that the workshop helped them connect theoretical concepts to practical applications, fostering a deeper understanding of how these technologies could be used to solve local problems. For example, one of the participants noted:

- "The workshop showed me how IoT and AI can be applied to improve agriculture and healthcare in my community. I now see how these technologies can solve real issues."

This feedback aligns with findings from Ratten and Usmanij [41], who argue that educational programs that demonstrate real-world applications enhance students' engagement and learning outcomes.

4.2.2 Impact of hands-on activities

The hands-on activities were frequently cited as the most impactful aspect of the workshop. Exercises such as brainstorming IoT-based solutions, developing pitches, and AI anomaly detection demonstration using Google Colab allowed participants to apply theoretical concepts in a practical setting. These activities not only reinforced learning but also boosted participants' confidence in their ability to use these technologies in real-world scenarios. For instance, a participant remarked:

- "The AI demonstration was incredibly insightful. It helped me see how machine learning can analyze data in real-time to detect anomalies.

Kolb's [24] experiential learning theory supports this finding, emphasizing the importance of active experimentation and reflective observation in facilitating deeper learning.

4.2.3 Collaborative learning

The group-based activities, such as brainstorming sessions and pitch development, fostered collaboration and peer learning. Participants valued the opportunity to work with peers from diverse academic backgrounds, which enriched their perspectives and encouraged innovative thinking. These activities also helped participants develop soft skills, such as teamwork and communication, which are critical for entrepreneurial success. For example, a participant observed:

- "Working with my group was a great experience. We combined our ideas to come up with a solution none of us would have thought of alone."

Research by Bell [4] highlights the role of collaborative learning in fostering creativity and critical thinking in entrepreneurial education.

4.2.4 Ethical awareness

While not the most frequently cited, ethical and societal concerns featured in several responses, particularly in relation to discussions about responsible innovation, AI fairness, and cybersecurity risks. These reflections indicate that students engaged with the broader implications of technology use, an important outcome in developing well-rounded, socially aware innovators. One participant shared:

- The part on responsible technology development was inspiring

This is consistent with the argument by [20, 21, 29] that ethical literacy should be a core component of technology education, especially in contexts where digital tools may exacerbate existing inequalities or vulnerabilities.

4.2.5 Suggestions for improvement

While most feedback was positive, participants also offered constructive suggestions for enhancing future iterations of the workshop. Common themes included requests for more time on practical activities, improvements to logistical aspects such as sound, and follow-up opportunities to deepen learning. Illustrative responses included:

- More practicals and timing.
- Just the sound system and additional time.
- Nothing in particular, the guest speaker was very good.

These suggestions highlight the importance of refining delivery logistics, session pacing, and post-workshop continuity; particularly for intensive one-day interventions with diverse participant backgrounds. Also, Table 3 presents the illustrative quotes organized by the core qualitative themes. These quotes highlight the richness and diversity of participant reflections and add further depth to the qualitative findings.

In sum, the qualitative findings reinforce the value of the workshop's experiential, interdisciplinary, and ethically grounded design. Participants not only acquired new knowledge but also reported increased confidence, practical insight, and motivation to explore technology-driven solutions within their local contexts. These findings validate the workshop's structure and offer practical guidance for future educational interventions aiming to foster innovation, collaboration, and social responsibility.

Table 3 Illustrative participant quotes by qualitative theme

Theme	Illustrative quotes
Content Relevance and Practicality	"The wider picture and deep explanation on the applications of IoT, AI, and Cybersecurity". "It gave me an insight on IOT and AI, also on how to implement it". "The part where the benefits of IoT were explained in practical terms was enlightening".
Hands-On Activities	"The group discussions and practical demonstration". "The exercises". "Learning about the concepts of cybersecurity and practical solutions".
Collaborative Learning	"The group discussions helped us understand how to think and solve problems together". "I think I enjoyed every bit of it, especially working with others on new ideas".
Ethical Awareness	"AI and helping to develop our poor landscape". "The part on responsible technology development was inspiring".
Suggestions for Improvement	"The students should have more opportunities to partake in activities such as the brainstorming". "Real life success stories about tech entrepreneurship ventures". "More activities".

5 Discussion

The findings from this study provide valuable insights into the effectiveness of experiential workshops in technology education, particularly in integrating IoT, AI, and cybersecurity to enhance learning outcomes, foster entrepreneurial thinking, and promote ethical awareness. This section discusses the implications of these findings, situating them within the context of existing literature and identifying areas for improvement and future research.

5.1 Interpretation of findings

The findings of this study provide compelling evidence for the efficacy of experiential and interdisciplinary learning models in advancing students' understanding of emerging technologies. The statistically significant improvements in participants' quiz scores, alongside high engagement and satisfaction levels, affirm the centrality of active learning in technology education. This is consistent with Kolb's [24] experiential learning theory, which posits that learning is maximized when individuals move through cycles of concrete experience, reflective observation, abstract conceptualization, and active experimentation. The structure of this workshop mirrored this cycle by integrating hands-on exercises, peer collaboration, and iterative project-based tasks.

Quantitative results indicated a mean knowledge gain of 25.5 percentage points, demonstrating substantial conceptual growth across IoT, AI, and cybersecurity. These improvements align with earlier findings by Biggs et al. [6], who noted that active engagement fosters deeper comprehension and improved retention. Importantly, the interdisciplinary design of the workshop enabled learners to move beyond siloed knowledge, facilitating a systems-level understanding of how AI can process IoT data and how cybersecurity ensures the integrity of these integrated systems. This holistic approach is critical in preparing students for real-world challenges and mirrors the pedagogical recommendations of Fayolle et al. [14] and Rafiq et al. [40] regarding the value of cross-domain learning.

High levels of participation in interactive components, such as brainstorming sessions, group design challenges, and pitch development exercises; further reinforced the value of learner-centered environments. Over 70% of participants engaged in collaborative activities, while 63% completed the hands-on exercises, reflecting the effectiveness of the workshop's design in fostering sustained attention and involvement. These patterns echo findings by Neck et al. [32], who emphasized the importance of learning through doing; particularly in entrepreneurial education contexts where creativity and iteration are essential.

The qualitative feedback added depth to these results, offering insight into participants' lived experiences of the workshop. Students highlighted how the content was not only relevant but immediately applicable to real-world problems within their communities. Participants offered examples of IoT-enabled healthcare systems, AI tools for optimizing agricultural resources, and secure data solutions; demonstrating their ability to contextualize abstract technological concepts into actionable ideas. These reflections support Ratten and Usmanij [41] and Nweke [34] assertion that student engagement is enhanced when learning is situated within familiar, socially meaningful contexts.

One of the most salient aspects of the workshop was its sustained attention to ethical and societal issues. Participants reported increased awareness of concerns such as data privacy, algorithmic bias, and cybersecurity vulnerabilities, often citing these topics as particularly impactful. Case-based discussions allowed students to consider the broader implications of technological design and deployment. This aligns with calls from [20, 21, 29] for embedding ethical reasoning into technology curricula as a way of fostering socially responsible innovation.

The combination of quantitative and qualitative findings offers strong validation for the workshop's design and implementation. By integrating interdisciplinary technical content, promoting collaborative, hands-on activities, and foregrounding ethical awareness, the workshop delivered a comprehensive educational experience that responded to the complex demands of technology education in the 21st century. These findings contribute to the growing literature advocating for constructivist, project-based, and ethically grounded approaches in STEM and entrepreneurial learning.

5.2 Implications for designing effective technology workshops

The results of this study offer a range of actionable insights for educators, instructional designers, and policymakers aiming to create impactful technology education experiences. The workshop's success demonstrates that by integrating hands-on engagement, interdisciplinary content, and ethical reflection, it is possible to cultivate technical proficiency, entrepreneurial mindset, and responsible innovation simultaneously. These implications highlight design principles that can guide the development of future workshops.

A key implication concerns the pedagogical power of hands-on activities. The statistically significant learning gains observed, alongside participants' qualitative endorsements; reaffirm that experiential learning significantly enhances conceptual understanding. Exercises such as Arduino-based IoT prototyping and AI-driven anomaly detection allowed participants to actively experiment with technologies and apply abstract concepts to tangible tasks. This aligns with Kolb's [24] experiential learning theory, which posits that learners best internalize new knowledge through cycles of action and reflection. To support this, future workshops should allocate sufficient time for guided technical application, ensure the availability of equipment, and provide facilitators capable of supporting diverse learner needs during practical exercises.

Secondly, the interdisciplinary integration of IoT, AI, and cybersecurity was critical in enabling learners to understand the interdependencies of modern technological systems. Rather than compartmentalizing knowledge into silos, the workshop modeled a systems-thinking approach that mirrors the challenges of real-world digital ecosystems. This aligns with Fayolle et al. [14] and Tariq [52], who argue that interdisciplinary education fosters creativity and prepares students for cross-functional collaboration. As such, educators designing future workshops should consider how multiple technological domains can be presented cohesively, encouraging participants to explore the synergies and tensions that exist between them.

The emphasis on ethical awareness also emerged as a vital component of the learning experience. Participants reported increased understanding of issues such as algorithmic bias, data privacy, and the societal impacts of AI-driven systems. These reflections underscore the importance of integrating ethical case studies, discussions, and scenario-based problem solving into the technical curriculum. As [20, 21, 29] suggest, technology education that omits ethical reasoning risks producing technically competent, but socially unaware, graduates. Therefore, ethical literacy must remain a core learning outcome in future experiential workshops.

Another implication involves the design for differentiated learning. Given the diverse prior experience levels of participants, it is essential that workshops accommodate novices and advanced learners alike. A modular structure, offering both foundational and advanced streams; can allow participants to tailor their learning experiences. Supplementary materials such as pre-recorded tutorials, readings, or preparatory quizzes can help level the playing field and optimize session time. This approach aligns with Barua and Lockee [3] who advocate for flexible learning design that responds to varying learner profiles in inclusive environments.

The workshop's emphasis on solving local problems also proved to be a powerful motivator. By encouraging participants to design context-specific solutions, such as AI-powered agricultural tools or IoT health monitoring systems; the workshop helped foster entrepreneurial thinking grounded in community relevance. This localized innovation strategy echoes the findings of Ratten and Usmanij [41], who argue that aligning education with local needs enhances learner engagement and promotes sustainable impact. Future workshops should continue to integrate problem-based learning anchored in the realities of participants' environments.

Finally, the workshop's success was facilitated by its use of accessible, low-cost, and open-source technologies. Platforms such as Arduino and Google Colab allowed for meaningful hands-on engagement without the need for expensive hardware or prior programming experience. These tools ensured inclusivity and are especially valuable in resource-constrained educational contexts. As noted by Ravet and Mtika [42], scalability and equity are critical design considerations for educational initiatives seeking broader impact. Thus, future workshops should leverage cost-effective tools and ensure that materials are adaptable to diverse settings and infrastructures.

Taken together, these implications point toward a model of technology education that is experiential, interdisciplinary, ethical, context-sensitive, and inclusive. A summary of these recommendations is provided in Table 4 to support the transferability of this model across institutions and regions.

5.3 Limitations and future directions

While this study offers promising evidence of the effectiveness of an experiential, interdisciplinary workshop on IoT, AI, and cybersecurity, it is important to acknowledge several limitations that temper the generalizability of its findings and suggest opportunities for further investigation and refinement.

A key limitation is the short-term focus of the study. The evaluation relied primarily on pre- and post-workshop assessments to measure immediate changes in knowledge, engagement, and participant satisfaction. While these metrics are valuable in assessing short-run impacts, they do not capture the long-term influence of the workshop on participants' professional development, entrepreneurial activities, or continued engagement with the subject matter. Future studies should adopt longitudinal research designs to assess how experiential learning experiences translate into sustained skill application, innovation capacity, or career choices over time.

Another limitation relates to the contextual specificity of the workshop. Conducted at Godfrey Okoye University in Enugu, Nigeria, the findings may be shaped by cultural, institutional, and infrastructural characteristics that are not universally generalizable. Although the participant group was academically diverse, the single-institution setting constrains broader inferences. Expanding the workshop model to include multiple institutions and geographic regions, particularly in both Global South and Global North contexts, would enhance understanding of how the model performs across varying sociocultural and educational environments.

The study also faced challenges related to the heterogeneity of participant backgrounds. While inclusivity was a design goal, the one-size-fits-all format inevitably struggled to meet the full range of learner needs. Some participants with limited prior exposure to technology found certain content areas challenging, while more advanced learners desired deeper technical engagement. The one-day duration of the workshop further limited the depth with which complex topics, such as machine learning, data encryption, or ethical risk mitigation; could be explored. Several participants suggested extending the workshop or offering follow-up sessions, which may enhance both accessibility and mastery.

Additionally, the use of self-reported qualitative feedback, while rich in narrative insight; introduces potential biases, such as social desirability effects and limited recall accuracy. Moreover, self-selection bias due to voluntary participation likely skewed the sample toward more motivated students as well as dropout between the pre- and post-quiz phases reduced the analytic sample size, which may affect generalizability. Future implementations should consider triangulating subjective responses with objective performance data, including skill assessments, peer evaluations, and instructor feedback. Project-based deliverables or rubrics could also provide more robust measures of learning outcomes and technical application.

To address these limitations, future research should explore the longitudinal impact of experiential workshops on learners' professional and entrepreneurial trajectories. This includes tracking participants' application of skills in real-world contexts, continued learning, or venture creation. Studies that expand to different institutional, national, or cultural contexts could also test the scalability and adaptability of the workshop model, revealing critical insights into how localized variables affect learning design and outcomes.

Table 4 Best practices for workshop design

Best Practice	Description
Hands-On Activities	Allocate significant time for practical exercises that reinforce concepts.
Interdisciplinary Approach	Integrate related domains to provide holistic understanding.
Ethical Considerations	Include discussions on societal and ethical implications of technologies.
Addressing Skill Diversity	Use modular designs and pre-workshop materials.
Focus on Local Relevance	Encourage solutions tailored to local challenges and opportunities.
Accessible Tools	Use affordable and scalable tools to ensure inclusivity.

future workshops would benefit from adopting a modular or tiered structure that allows participants to engage at an appropriate skill level. Such scaffolding could support novices while offering technical depth and real-world challenges for advanced learners. Extended formats or hybrid models (e.g., multi-day events or pre/post digital modules) may also enable deeper exploration of interdisciplinary topics and facilitate cumulative skill development.

Finally, as emerging technologies continue to evolve, future workshops should integrate advanced topics, such as edge computing, quantum-safe security, and machine learning deployment pipelines, while continuing to emphasize ethical and societal dimensions of innovation. Case-based learning, scenario simulations, and structured debate formats can enrich ethical discussions. Improved data collection, including project-based evaluations, longitudinal tracking, and mixed-method analytics; will further strengthen program assessment and support the continuous evolution of experiential education in technology and entrepreneurship.

6 Conclusion

This study examined the design, implementation, and impact of an experiential workshop that integrated IoT, AI, and cybersecurity to promote interdisciplinary learning, entrepreneurial awareness, and ethical engagement. The results provide strong evidence for the effectiveness of experiential learning in bridging the gap between theoretical instruction and real-world application. Participants demonstrated statistically significant knowledge gains, with quiz scores increasing by an average of 25.5 percentage points across all domains, which affirms the pedagogical value of active learning strategies grounded in Kolb's experiential learning model.

The findings also underscore the impact of collaborative learning environments and interdisciplinary integration. Hands-on exercises, such as AI-based anomaly detection and IoT prototyping, were identified as particularly valuable in reinforcing conceptual understanding. Group-based problem-solving activities encouraged participants to co-develop innovative solutions, strengthening communication, teamwork, and critical thinking skills. Importantly, the workshop's holistic design enabled learners to understand how IoT, AI, and cybersecurity interact within technological ecosystems, supporting systems-level thinking essential for tackling complex societal problems.

Moreover, the workshop effectively fostered entrepreneurial thinking, particularly by guiding participants to develop solutions tailored to local challenges in healthcare, agriculture, and digital services. This localized focus increased engagement and reinforced the social relevance of technological innovation. Simultaneously, the integration of ethical reflection, through case discussions on data privacy, algorithmic bias, and cybersecurity vulnerabilities; helped cultivate a mindset of responsible innovation, aligning with global calls for more socially aware technology education.

This study contributes to emerging research in technology education and entrepreneurial pedagogy by demonstrating the potential of interdisciplinary, experiential workshops to cultivate essential 21st-century skills. It also provides a scalable and inclusive educational model, leveraging accessible tools like Arduino and Google Colab; that can be implemented across diverse learning environments and socio-economic contexts.

While the study captured immediate learning outcomes, future research should explore the long-term effects of such interventions, including their influence on career trajectories, startup creation, and sustained engagement with emerging technologies. Replicating and adapting the workshop across different cultural, institutional, and geographic settings would offer critical insights into its scalability, adaptability, and enduring educational value.

In summary, this research affirms that interdisciplinary, experiential, and ethically grounded workshops can play a transformative role in preparing students for the challenges and opportunities of technology-driven futures. As the demand for innovation-ready graduates continues to rise, educational strategies that foster technical competence, entrepreneurial initiative, and ethical awareness will be essential for building inclusive, resilient, and responsible digital societies.

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Declarations

Ethics approval and consent to participate This study was conducted in accordance with the Guidelines for Research Ethics in the Social Sciences and the Humanities. Godfrey Okoye University Research Committee has confirmed that no additional ethical approval was required for this research. No health or other personal data were collected. Written consent to participate and written consent to publish were obtained from all participants.

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