



E-learning International Conference



Transforming Education through Responsible
Innovation and Inclusion in the Digital Era

CONFERENCE PROCEEDINGS

Proceedings of the E-Learning International Conference,
Kumasi, Ghana.

EDITORS:

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DATE:

Thursday - Friday,
24th - 25th July 2025

KNUST, Kumasi

TRANSFORMING EDUCATION THROUGH RESPONSIBLE INNOVATION AND INCLUSION IN THE DIGITAL ERA

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Proceedings of the E-Learning International Conference, Kumasi, Ghana

24-25 July 2025

ISBN 978-9988-51-611-6

Published by the KNUST E-Learning Centre

E-Learning International Conference,

KNUST E-Learning Centre

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Leveraging Digital Tools For Inclusive And Contextualised Teaching Of Core Mathematics In Pre-Tertiary TVET: A Ghanaian Perspective

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ABSTRACT:

Core Mathematics remains a persistent challenge in Ghana's pre-tertiary Technical and Vocational Education and Training (TVET) institutions, particularly for learners in under-resourced environments. This study investigates how digital tools can be leveraged to enhance inclusive and contextually relevant mathematics instruction in these settings. Employing an explanatory sequential mixed-methods design, the research analysed survey responses from 137 mathematics facilitators, exit examination performance data from participating schools, and qualitative insights from focus group discussions with mathematics facilitators. Findings revealed that rural schools significantly lag behind their urban counterparts in mathematics achievement due to infrastructural limitations, with statistically significant differences observed ($H=21.58$, $p=0.00576$). Only 2% of deprived schools had functional ICT labs, and over 85% of facilitators cited unreliable electricity and poor internet connectivity as major barriers. Furthermore, facilitators reported that most digital tools lacked cultural and vocational relevance, with the lowest perception score (1.72) recorded for the ability of digital tools to bridge theory and practice. Nonetheless, facilitators who demonstrated strong integration of technological and pedagogical knowledge achieved higher learner gains ($\beta=0.47$, $p=0.02$), underscoring the relevance of the TPACK framework. A new construct, "infrastructural pedagogical knowledge", emerged as essential for teaching in resource-constrained environments. The study recommends urgent policy actions, including (1) the development of localized, offline-compatible digital content; (2) national investments in rural electrification and broadband expansion through public-private partnerships with telecom firms; (3) targeted professional development to build facilitator competence in contextualized digital pedagogy; and (4) gender-sensitive digital interventions such as subsidized devices for female learners and mentorship programs for female facilitators.

KEYWORDS: Digital inclusion, TVET mathematics, Curriculum alignment, Infrastructural pedagogy, Gender equity, Contextualized instruction.

1. Introduction

In the digital era, integrating technology into education is no longer a peripheral innovation, instead it is a fundamental strategy to enhance learning outcomes and ensure equity (Eden et al., 2024). This is especially critical for Technical and Vocational Education and Training (TVET) institutions, which aim to equip learners with both academic knowledge and practical competencies needed for today's workforce. In Ghana, Core Mathematics is a compulsory subject within pre-tertiary TVET curricula and plays a foundational role in shaping learners' cognitive, analytical, and problem-solving capacities. However, it remains a persistent barrier to learner achievement, particularly in under-resourced settings (Fokuo et al., 2022; Bofo, 2017; Frempong & Asare-Bediako, 2016).

Although Ghana has undertaken multiple reforms, including curriculum standardization, infrastructure upgrades, and ICT policy rollout, to revamp the pre-tertiary TVET sector in support of national industrialization (Donani et al., 2021), mathematics instruction remains largely traditional, decontextualised, and facilitator-centred (Atteh, 2023). Digital tools, which hold promise for enhancing interactivity, personalising learning, and making abstract concepts more tangible, have not been widely or effectively integrated into classroom practice (Gyaase et al., 2020). Facilitators often revert to conventional methods, and learners, particularly in rural and deprived areas, continue to struggle with comprehension, relevance, and engagement (Fleury, 2023).

The specific problem this study addresses is the ineffective, inequitable, and insufficiently contextualized integration of digital tools in Core Mathematics instruction across Ghanaian pre-tertiary TVET institutions. While educational technologies are increasingly available in theory, their transformative potential remains unrealized due to infrastructural deficits, limited facilitator training, and a lack of culturally and vocationally relevant digital content.

Globally, studies show that digital tools can improve mathematics learning, especially when adapted to learner needs and local contexts. In Ghana, Henkel et al. (2024) demonstrated that AI-powered tutors like Rori significantly improve learner achievement. Similarly, Zwart et al. (2017) found that interactive platforms enhance understanding in vocational education. Eden et al. (2024) and Asgarov & Badalova (2024) argued that inclusive digital tools bridge learning gaps and foster engagement in transitional systems. However, these successes are often recorded in relatively well-resourced environments. Infrastructural and socio-cultural barriers, such as unreliable electricity, limited digital literacy, and gendered access to devices, continue to marginalize learners in rural areas and compound educational inequities (UNESCO, 2025a; Gyaase et al., 2020; Ghana News Agency, 2025).

This study contends that unless digital tools are intentionally designed, localized,

and implemented with pedagogical and infrastructural awareness, they risk amplifying existing disparities rather than improving outcomes. Using the Technological Pedagogical Content Knowledge (TPACK) framework (Koehler & Mishra, 2009), the study investigates the realities of digital tool integration in Core Mathematics instruction across diverse pre-tertiary TVET contexts in Ghana. It adopts a mixed-methods approach to examine four core research questions:

1. What is the state of digital tools availability and usage in Core Mathematics instruction?
2. How do facilitators perceive the inclusivity and contextualization of Core Mathematics instruction?
3. Is there a statistically significant difference in the mean mathematics achievement of urban, peri-urban, and rural pre-tertiary TVET institutions in Core Mathematics exit examinations?
4. What strategies can be employed to effectively use digital tools in creating inclusive and contextualized mathematics instruction that improves learner engagement and performance?

Through the exploration of these questions, this study contributes to both theory and practice by offering context-specific insights and policy-relevant recommendations for improving mathematics education in Ghanaian TVET institutions through digital innovation.

2. Literature Review

2.1 Theoretical Framework: Technological Pedagogical Content Knowledge (TPACK)

This study is anchored in the Technological Pedagogical Content Knowledge (TPACK) framework developed by Koehler and Mishra (2009), which emphasizes the interconnectedness of content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). In the context of pre-tertiary TVET in Ghana, TPACK provides a conceptual foundation for understanding how facilitators integrate digital tools into mathematics instruction. However, the current study extends the model by proposing “infrastructural pedagogical knowledge”, which is defined as the competence to adapt pedagogy and technology to infrastructural constraints; a dimension necessary for educators operating in digital-resource-constrained environments. This adaptation acknowledges that effective integration of digital tools in under-resourced TVET settings requires not only technological fluency but also creativity and improvisation to overcome infrastructural deficits.

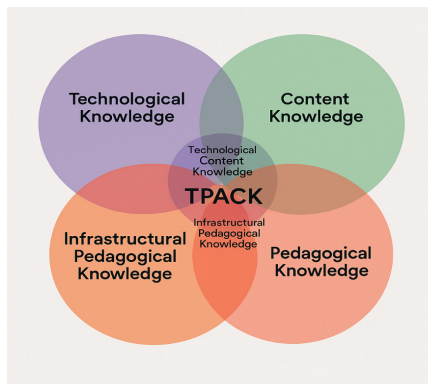


Fig. 1 Revised TPACK framework with Infrastructural Pedagogical Knowledge

2.2 Global Promising Practices in Digital Mathematics Education

Across global contexts, research consistently underscores the transformative potential of digital tools for enhancing mathematics instruction. Zwart et al. (2017) demonstrated how interactive platforms significantly improve conceptual understanding in vocational education, particularly when such tools are tailored to learners' specific needs. Similarly, Henkel et al. (2024) documented the effectiveness of an AI-driven math tutor in Ghana, highlighting substantial gains in learner achievement.

Other studies stress inclusivity. Eden et

al. (2024) advocate for equity-focused digital systems that bridge socio-economic gaps, while Asgarov and Badalova (2024) emphasize adaptability in transitional and post-Soviet education systems. These insights reinforce a broader consensus: digital interventions are most effective when they are localized, adaptive, and context-sensitive. Nonetheless, these promising models often emerge from well-resourced settings or short-term pilot interventions. The transferability of such solutions to environments like rural Ghana, where electricity, connectivity, and digital literacy remain major obstacles, is limited. This study builds on these global findings by examining the real-world application of similar tools in Ghanaian TVET institutions and identifying where implementation breaks down due to contextual constraints

2.3 Challenges in Digital Integration: The Ghanaian Experience

While Ghana has invested in ICT policy and TVET reform (Donani et al., 2021), substantial challenges hinder meaningful integration of digital tools into mathematics instruction. Gyaase et al. (2020) note that implementation is often hampered by poor infrastructure and limited facilitator preparedness. Only 2% of deprived schools have functional ICT labs (The Business & Financial Times, 2025; African Education Watch, 2025), and frequent power outages restrict the use of even basic digital resources. Socio-cultural barriers compound these technical challenges. Gender disparities, for example, continue to limit female learners' access to technology (UNESCO, 2025a). Language and curriculum misalignment also limit contextualization, with most digital tools failing to reflect local knowledge systems or vocational realities. The study supports these observations by showing that, despite moderate usage of digital tools by facilitators, the lack of contextual and inclusive content rendered these tools pedagogically ineffective. The perception data from the respondents, especially the low scores on the relevance of digital content and its ability to bridge theory and practice, confirms a widespread dis-

connect between digital innovation and vocational pedagogy in Ghana.

2.4 Gaps and Limitations in Current Literature

Existing literature consistently highlights the potential of digital tools to enhance mathematics education when thoughtfully integrated into pedagogy and adapted to learners' contexts. Evidence suggests that technology can improve learner engagement, conceptual understanding, and academic performance, especially in TVET settings where applied, interactive learning is critical (Zwart et al., 2017; Henkel et al., 2024). Moreover, there is increasing recognition of the need for inclusive digital design and content localization to bridge socio-economic and geographical divides (Eden et al., 2024; Asgarov & Badalova, 2024). In Africa, studies from countries such as Nigeria, Kenya, and Uganda reveal common structural challenges in integrating digital tools into TVET education. Ogudo et al. (2024) identify persistent infrastructural deficits in Nigeria, notably unreliable electricity and poor internet access. In Kenya, Marangu et al. (2022) report that despite supportive digital learning policies, TVET facilitators often lack adequate training and support. Similarly, Muinda et al. (2024) highlight Uganda's efforts to enhance digital capacity but note that high student-computer ratios and non-contextualised content hinder effective implementation. These findings point to the importance of context-responsive strategies rather than uncritical adoption of global models. Despite these insights, several key gaps remain. Much of the research is based on pilot projects or relatively well-resourced institutions, resulting in limited empirical evidence from under-resourced or rural pre-tertiary TVET settings in sub-Saharan Africa. This raises concerns about the generalizability of current best practices. Additionally, few studies explore digital integration holistically by considering infrastructure, pedagogy, and equity in tandem. Critical contextual factors such as unreliable power, limited internet, and linguistic mismatches are often underexplored, as are the perspectives of facilitators and learners regarding inclusivity and relevance. This study addresses these gaps by providing a context-specific analysis of digital integration in Ghanaian pre-tertiary TVET mathematics classrooms. It incorporates both quantitative and qualitative insights, emphasizing the lived experiences of teachers and learners. By situating Ghana's experiences alongside those of Nigeria, Kenya, and Uganda, the study introduces the concept of infrastructural pedagogical knowledge—a framework that highlights resilience and improvisation as essential competencies for digital teaching in low-resource environments. While TPACK-XL (Joya et al., 2024) addresses leadership, our construct focuses on resource constraints, this dimension extends the TPACK framework, offering a more nuanced lens for educational technology research across sub-Saharan Africa.

2.5 Contribution to the Field and Theoretical Advancement

This study contributes both practically and theoretically to the discourse on digital pedagogy in developing contexts. Practically, it offers actionable insights for policymakers, suggesting the urgent need for localized digital content, targeted facilitator training, and infrastructure investment. Theoretically, it refines the TPACK model by introducing the concept of infrastructural pedagogical knowledge, underscoring the need for adaptability and innovation among educators in under-resourced environments. In highlighting how facilitators improvise with offline tools and adjust pedagogy based on infrastructural realities, the study provides a model for scalable, equitable digital transformation. These insights are critical not just for Ghana but also for other countries grappling with similar digital divides in education.

3. Research Methodology

3.1 Research Approach and Design

The current study employed a mixed-methods approach using an explanatory sequential design, which involved two distinct phases: an initial quantitative phase followed by a qualitative phase. The rationale for this approach lies in its capacity to provide both breadth and depth of understanding (Creswell & Creswell, 2018). The quantitative phase was used to examine the availability and usage of digital tools, facilitators' perceptions, and learner performance data in Core Mathematics across selected pre-tertiary TVET institutions in Ghana. Following this, the qualitative phase explored in greater depth the patterns and anomalies identified in the quantitative data. The mixed-methods strategy was selected to combine the strengths of both quantitative and qualitative methodologies while addressing their respective limitations. According to Creswell and Plano Clark (2018), such integration enhances the validity and reliability of findings by allowing one method to inform or clarify the results of the other. In this study, descriptive and inferential statistics were applied to the quantitative data collected via questionnaires and learners' Core Mathematics exit examination results. The qualitative component involved thematic analysis of focus group discussions, which provided nuanced insights into facilitators' strategies, challenges, and contextual experiences regarding the use of digital tools in instruction. Despite acknowledged limitations of the mixed-methods approach, such as potential methodological complexity and resource intensiveness, it was deemed suitable for addressing the multifaceted nature of digital tool integration within Ghana's diverse TVET educational landscape. The approach enabled the researchers to move beyond surface-level trends to uncover underlying dynamics that influence inclusive and contextually relevant mathematics teaching.

3.2 Population

The population for this study included all the two-hundred and thirteen (213) Core Mathematics facilitators from selected pre-tertiary TVET institutions across six

regions in Ghana. The six regions were chosen using purposive sampling to ensure geographical, socio-economic, and educational diversity.

3.3 Sample and Sampling Techniques

The study employed a stratified and purposive sampling strategy to ensure representativeness and minimize sampling error. Using the Cochran formula (Cochran, 1977) with a 5% margin of error and a 95% confidence interval, a sample size of 137 mathematics facilitators was determined to be statistically adequate for inferential analysis. This sample size was considered sufficient to reflect the diversity of Ghana's pre-tertiary TVET sector while maintaining statistical power. To reduce sampling error, which is an inherent limitation in probability sampling (Irwin et al., 2019), the sampling process incorporated stratification based on geographical location—specifically urban, peri-urban, and rural classifications (Yu et al., 2024). All participating institutions were grouped into these three strata. From each stratum, three institutions were randomly selected, making a total of nine (9) schools. This approach was adopted to reduce bias and enhance the representativeness of the institutional sample.

In selecting the schools, efforts were made to reflect vocational heterogeneity by drawing institutions from agro-industrial, coastal, and mining economies. Furthermore, to account for regional variation, schools were purposively selected from six geographically and socio-economically diverse regions across Ghana. This ensured that the sample captured variations in infrastructural development, digital access, and educational investment, offering a nuanced picture of the national TVET landscape. Finally, 137 mathematics facilitators were randomly sampled from these schools. This ensured that the individual-level data collected was representative across the different geographical strata and institutional contexts, providing a solid foundation for generalizing findings across Ghana's pre-tertiary TVET system.

3.4 Data Collection Instruments

Three primary instruments, tailored to the research questions, were used to gather data for the study. First, a structured questionnaire was administered to Core Mathematics facilitators to assess the availability and usage of digital tools, as well as their perceptions regarding inclusivity and contextualization of instruction. This questionnaire consisted of closed-ended items and was designed to elicit quantitative data for statistical analysis. Furthermore, a focus group interview guide was employed to collect qualitative data from selected mathematics facilitators. This interview was conducted to gain deeper insights into the strategies, experiences, and challenges associated with using digital tools to create inclusive and contextualized learning environments. All instruments were developed with reference to established tools from similar studies (e.g., Buabeng-Andoh, 2012; Agyei & Voogt, 2011) and adapted to the Ghanaian TVET context to ensure relevance and appropriateness.

3.5 Validity and Reliability of Instruments

The content validity of the questionnaire and test instrument was established through expert review by professionals in mathematics education and educational technology. A pilot study was conducted in a comparable institution with three mathematics facilitators, and Cronbach's alpha was used to measure internal consistency reliability of the questionnaire, achieving a coefficient of 0.81, which indicates good reliability (Taber, 2018). Validity of the qualitative instrument was ensured through peer review, and expert validation.

3.6 Data Collection, Processing, and Analysis Procedure

Data collection was conducted over six weeks, beginning with ethical clearance and institutional approvals. Questionnaires were administered to facilitators, and learner performance data from 2011 to 2020 exit examinations were gathered from participating institutions. In the final week, focus group discussions were conducted using a semi-structured guide and audio recorded with participants' consent. Quantitative data were coded and analysed using SPSS version 23. Descriptive statistics such as means and standard deviations were computed. A box-plot revealed a violation of normality; thus, the Kruskal-Wallis' test was employed to compare group perception scores across urban, peri-urban, and rural settings for the first three research questions. The fourth research question was addressed through qualitative data from the focus groups, which were transcribed verbatim and analysed thematically using Braun and Clarke's (2006) six-step framework.

3.7 Trustworthiness of Qualitative Data

To ensure the credibility and trustworthiness of the qualitative findings, the study adhered to credibility and dependability from the four criteria by Lincoln and Guba (1985). Credibility was enhanced through triangulation by integrating qualitative focus group data with quantitative survey and performance data. Member checks were conducted during the focus group discussions by summarizing participants' statements for confirmation and clarification. Dependability was addressed by maintaining a clear audit trail of the research process, including documented procedures for data collection, coding, and analysis. Thematic analysis followed Braun and Clarke's (2006) six-step framework to ensure consistency.

3.8 Ethical Considerations

The study adhered to ethical standards for research involving human subjects in accordance to the dictates of the clearance obtained from the Social Sciences Research Ethics Committee at the College of Humanities and Social Sciences of KNUST with reference number HuSSREC/AP/57/VOL. 3. Participants were briefed on the purpose and procedures of the study and gave informed consent before participation. Participant anonymity was maintained by anonymizing survey responses, and data were stored on password-protected servers. They were further assured that the data were solely meant for research purposes.

4. Findings and Discussion

The discussion draws directly from the theoretical lens of the TPACK framework, alongside empirical evidence from global and local literature, to unpack the complex interactions among infrastructure, pedagogy, and learner outcomes.

4.1 Demographics

The demographic profile of the participating mathematics facilitators, predominantly male (83.21%) with moderate teaching experience (61.31% having 1-10 years) and a majority holding a B.Ed. (55.47%), provides a crucial context for interpreting the study's findings. While these statistics offer a snapshot of the teaching force, the significant gender imbalance among educators, coupled with later findings regarding gender disparities in learner access to digital tools (male learners accessing mobile practice apps 1.7 times more frequently), underscores a broader systemic challenge. This aligns with UNESCO's observations (2025a, 2025b) regarding the persistent digital gender gap in sub-Saharan Africa, where socio-cultural norms and economic barriers disproportionately affect girls' engagement with technology. Understanding the characteristics of the teaching body is essential for designing targeted professional development initiatives that address not only technological skills but also gender-responsive pedagogy, as advocated by UNESCO (2025a).

4.2 Digital Tools Availability and Usage in Core Mathematics Instruction

The data revealed a pervasive inadequacy in digital infrastructure across surveyed institutions, especially in rural areas. Facilitators rated infrastructure availability poorly (mean score = 3.94), echoing national reports that only 2% of deprived basic schools have functional ICT labs (Africa Education Watch, 2025). Unreliable electricity and limited access to internet connectivity were cited by over 85% of facilitators as significant constraints, a finding consistent with Gyaase et al. (2020), who noted that digital integration in Ghanaian classrooms remains largely aspirational due to infrastructural deficits. This stark reality limits the implementation of promising digital tools such as GeoGebra or AI-driven tutors like Rori (Henkel et al., 2024), whose effectiveness presuppose stable access to devices and connectivity. The mismatch between national ICT policies and ground-level realities demonstrates a key issue raised in the literature: policy intent does not translate into pedagogical transformation without robust infrastructural support.

4.3 Perception of Inclusivity and Contextualization of Core Mathematics Instruction

A critical issue emerging from both the literature and the current data is the poor localization and inclusivity of digital tools. Facilitators overwhelmingly disagreed that digital resources supported diverse learning needs (score = 3.56) or reflected local realities (score = 3.83). Most notably, the lowest score (1.72) was recorded for

the perception that tools helped bridge theory and practice, a central mandate of TVET education. This finding parallels Eden et al. (2024) and Asgarov & Badalova (2024), who emphasized that without cultural and local relevance, digital interventions are unlikely to promote equity and engagement. The results also corroborate Almeda (2023), who noted the importance of embedding indigenous knowledge and vocational relevance into instructional materials. The absence of tools in local languages and the lack of vocationally anchored digital simulations are significant barriers to contextualization.

4.4 Disparities in Mathematics Achievement Across Geographical Locations

Table 1: Summary of Mathematics Achievement

School Type	Average Pass Rate (%) by School type	Std. Dev. by School	Average Score by Geographical location	Standard Deviation
Urban				
School A	50.87	9.48	49.50	7.36
School B	49.02	7.17		
School C	48.60	3.32		
Peri-urban				
School A	41.11	6.38	43.61	5.99
School B	43.82	9.65		
School C	45.91	4.46		
Rural				
School A	40.03	3.70	41.85	4.63
School B	44.29	4.62		
School C	41.22	7.09		

The Kruskal-Wallis’ test confirmed a statistically significant difference in Core Mathematics exit examination pass rates among urban, peri-urban, and rural pre-tertiary TVET institutions ($H=21.58$, $p=0.00576$), with a specific significant difference between Urban School C and Rural School A ($p=0.02098$), serves as empirical evidence of the profound impact of the digital divide on educational equity. This finding is not an isolated anomaly but is strongly supported by a growing body of literature. Research on school electrification in Ghana has demonstrated that access to electricity is a crucial mediating factor for improving academic performance in deprived districts, with Adamba (2017) reporting a 37.5% increase in mathematics pass rates due to rural electrification (Adamba, 2018). Beyond Ghana, studies in Senegal (Magbonde et al., 2025) and among BRICS countries (Akram,

2022) consistently link improved access to electricity with enhanced educational outcomes, including increased school attendance and study duration. This highlights fundamental infrastructural disparities, such as reliable electricity and internet access, are not merely inconveniences but direct determinants of academic success, perpetuating educational inequities across geographical divides.

4.5 Strategies for Effective Digital Tool Integration and Persistent Challenges

Table 2: Summary of actionable strategies

Challenge	Short-term Solution	Long-term Policy
Electricity outage	Offline apps + Solar-powered devices	National school electrification program
Gender gap	Female-only tech labs + mentorship	Gender quotas in STEM teacher recruitment

The focus group interviews revealed both the promise and the challenges of using digital tools in Ghanaian TVET education. Facilitators praised tools like GeoGebra for transforming pedagogy by promoting collaboration and deeper conceptual understanding, supporting prior findings on the benefits of interactive and AI-enhanced learning tools. However, significant challenges hinder effective implementation, especially in rural areas. While many facilitators (63%) attempted to contextualize digital content, they struggled with poor infrastructure, with 92% citing unreliable electricity and 85% noting a lack of local language support in digital tools. These issues align with the broader digital divide in Ghana, where limited connectivity and high costs obstruct rural digital integration. Equity concerns also emerged, highlighting a "digital readiness gap" shaped by cognitive, infrastructural, and socio-cultural factors. Low prior exposure to technology increased cognitive burden among 41% of learners, emphasizing the need for foundational digital literacy. Disparities between urban (89%) and rural (33%) internet access directly affect learning outcomes. Additionally, gender inequalities persist: male learners accessed mobile learning apps 1.7 times more than females, a trend reflecting broader barriers faced by girls in accessing technology, with serious consequences for their future in STEM and economic empowerment.

To bridge the gender gap in mathematics education, particularly in Technical and Vocational Education and Training (TVET), gender-sensitive interventions must be prioritized through deliberate policy actions. One key strategy is the targeted recruitment and training of female mathematics facilitators who can serve as role models and help reduce implicit gender bias in instruction. Ensuring equitable ac-

cess to technology is also essential; this can be achieved through the provision of subsidized or free digital devices to female learners, especially in rural areas, alongside community sensitization efforts to overcome cultural resistance. Additionally, developing digital content in local languages that incorporates gender-inclusive scenarios will enhance relevance and engagement for female learners. Teacher professional development should also be strengthened to include gender-responsive pedagogy and effective strategies for equitable digital engagement. Finally, partnerships with organizations such as UNESCO and Girls in ICT can support the launch of after-school digital literacy programs tailored for girls in TVET institutions, fostering a more inclusive and empowering learning environment.

These interventions align with the global call to close the gender digital divide (UNESCO, 2025a) and enhance the inclusive potential of digital learning tools in STEM education for all learners.

4.6 Synthesis with Theoretical Framework

The TPACK model (Koehler & Mishra, 2009) proved invaluable in elucidating the variations in implementation success. The finding that facilitators with integrated technological-pedagogical knowledge achieved significantly higher learner gains ($\beta=0.47$, $p=0.02$) through the use of apps like Khan Academy Lite during power outages, strongly reinforces TPACK's core tenet: effective technology integration requires a synergistic understanding of content, pedagogy, and technology. This aligns with broader literature emphasizing that digital competence in education extends beyond mere technical proficiency to encompass the thoughtful application of technology to enhance teaching and learning (Nadapdap, 2025).

Crucially, this study extended the TPACK framework by revealing an underemphasized, yet vital, dimension: infrastructural pedagogical knowledge. This reflected facilitators' ability to improvise and innovate despite limited resources (e.g., utilizing offline mobile applications), which significantly correlated with rural learner outcomes ($r=0.58$). In contexts characterized by significant infrastructural limitations, such as those prevalent in Ghanaian TVET, a facilitator's capacity to creatively navigate and overcome these challenges becomes a critical component of their overall digital pedagogical competence. This "infrastructural pedagogical knowledge" is not explicitly detailed in the original TPACK model but is indispensable for achieving equitable and sustainable digital integration in resource-constrained environments. This finding offers a valuable theoretical contribution, suggesting a necessary adaptation of the TPACK framework for educational technology research and practice in developing countries, where resourcefulness in the face of adversity is paramount for successful digital transformation.

5. Conclusion and Further Research

This study established that digital tools have the capacity to significantly transform Core Mathematics instruction in Ghana's pre-tertiary TVET institutions. However, their potential is currently obstructed by entrenched infrastructural deficits, inadequate pedagogical integration, and deep-rooted socio-cultural barriers. These challenges are not peripheral; they are central impediments to equitable and effective mathematics education. Immediate and targeted interventions are imperative: the digital divide must be closed, facilitator digital competence must be systematically strengthened, and the development of contextually relevant, locally-grounded digital resources must be prioritized as a national educational mandate. Without these actions, digital innovation will continue to bypass the very learners it aims to uplift.

To address these systemic barriers, cross-sector collaboration is crucial. Ministries of Education and Communication must work in tandem with private telecom providers to expand broadband infrastructure, especially in rural and peri-urban areas. Partnerships with ICT firms, NGOs, and local community leaders can also support the deployment of offline-capable learning tools, mobile-enabled content, and solar-powered digital devices. Gender-responsive digital pedagogy must also be prioritized in national TVET reforms. These efforts should be guided by inclusive policies that emphasize equity, relevance, and sustainability. By leveraging the strengths of both public and private actors, Ghana can build a resilient digital education ecosystem that serves all TVET learners, regardless of geography or gender. Further research should prioritize longitudinal studies to examine the long-term impact of digital tool integration on learner outcomes and facilitator development. Additionally, more in-depth qualitative investigations are needed to explore the lived experiences of educators and learners in marginalized communities. Future work could also focus on designing, piloting, and scaling up sustainable models for digital integration tailored to the needs and constraints of TVET institutions across Ghana and comparable contexts.

6. Acknowledgement

The researchers acknowledge the crucial contributions of the principals for providing learner performance data, which was essential for the quantitative phase, and the mathematics facilitators for sharing their experiences and insights, which enriched the study's findings.

7. References

- Adamba, C. (2017). Effect of school electrification on learning outcomes: a sub-national level analysis of learners' pass rate in English and mathematics in Ghana. *Education Research Policy Practice*, 17, 15-31. <https://doi.org/10.1007/s10671-017-9215-1>
- Adamba, C. (2018). Rural electrification and educational outcomes in Ghana. *Journal of Energy and Development*, 43(1), 101-118.
- Africa Education Watch. (2025). Eduwatch Report on ICT Infrastructure in Basic Schools. Retrieved from <https://africaeducationwatch.org/publication/esmt-dp-review-2025>
- Agyei, D. D., & Voogt, J. M. (2011). Exploring the potential of the will, skill, tool model in Ghana: Predicting prospective and practicing teachers' use of technology. *Computers & Education*, 56(1), 91-100. <https://doi.org/10.1016/j.compedu.2010.08.017>
- Akram, V. (2022). Causality Between Access to Electricity and Education: Evidence from BRICS Countries. *Energy RESEARCH LETTERS*, 3(2), <https://doi.org/10.46557/001c.32597>
- Almeda, J. A. B. (2023). Contextualization of Indigenous Knowledge in the Selected Elementary Schools. *International Journal for Multidisciplinary Research*. 5(5), 1-32. Retrieved from <https://www.ijfmr.com/papers/2023/5/6504.pdf>
- Asgarov, T., & Badalova, N. (2024). Digital Tools in Education. *Elmi Tədqiqat*, 4(12), 37-42. <https://doi.org/10.36719/2789-6919/40/37-42>
- Atteh, E. (2023). The Recommended Instructional Approach in Ghanaian Basic Schools; A Review of Constructivist Approach of Teaching and Learning in the Mathematics Classroom. *Asian Journal of Education and Social Studies*. <https://doi.org/10.9734/ajess/2023/v47i11013>
- Boafo, F. A. (2017). The Impact of Mathematics on Academic Performance of Students in TVET Institutions in Ghana. *African Journal of Applied Research*, 2(2), 110-120. <https://ajaronline.com/index.php/AJAR/article/view/223>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101. <https://doi.org/10.1191/1478088706qp063oa>
- Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). John Wiley & Sons.
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed meth-*

ods research (3rd ed.). SAGE Publications.

Donani, M., Saan, R., Kuuyine, F., & Adams, Y. (2021). An empirical study discussing industrialisation and technical education in Ghana. *International Journal of Vocational and Technical Education*, 13(1), 1–12.

<https://doi.org/10.5897/IJVTE2021.0297>

Eden, C. A., Chisom, O. N., & Adeniyi, I. S. (2024). Harnessing technology integration in education: Strategies for enhancing learning outcomes and equity. *World Journal of Advanced Engineering Technology and Sciences*.

<https://doi.org/10.30574/wjaets.2024.11.2.0071>

Fleury, M. A. (2023). Rural Special Educators and the Need for Facilitative Skills (pp. 226–251). IGI Global.

<https://doi.org/10.4018/978-1-6684-7437-2.ch012>

Fokuo, M., Lassong, B. S., & Kwasi, S. F. (2022). Students' Poor Mathematics Performance in Ghana: Are there Contributing Factors? *Asian Journal of Education and Social Studies*, 16–21.

<https://doi.org/10.9734/ajess/2022/v30i430729>

Frempong, M., & Asare-Bediako, M. (2016). Performance Assessment of Mathematics and Statistics Students of a Tertiary Institution in Ghana. *Mathematical Theory and Modeling*, 6(6), 135–142.

<https://www.iiste.org/Journals/index.php/MTM/article/download/31434/32274>

Ghana News Agency. (2025, May 21). Half of TVET learners unaware of digital programmes in their schools. Retrieved from

<https://gna.org.gh/2025/05/half-of-tvet-learners-unaware-of-digital-programmes-in-their-schools/>

Gyaase, P. O., Gyamfi, S. A., Kuranchie, A., & Koomson, F. S. (2020). The Integration of Information and Communication Technology in Pre-University Education in Ghana: A Principal Component Analysis (pp. 109–123). IGI Global.

<https://doi.org/10.4018/978-1-7998-0238-9.CH009>

Henkel, O., Horne-Robbinson, H., Kozhakhmetova, N., & Lee, A. (2024). Effective and Scalable Math Support: Experimental Evidence on the Impact of an AI-Math Tutor in Ghana. In *Artificial Intelligence in Education* (pp. 344–355). Springer. https://doi.org/10.1007/978-3-031-64315-6_34

- Irwin, P. L., He, Y., & Chen, C.-Y. (2019). Deconvolution of the Error Associated with Random Sampling. *Advances in Pure Mathematics*, 09(3), 205–227. <https://doi.org/10.4236/APM.2019.93010>
- Joya, L. G., Merchan, M. A. M. & Barrera, E. A. L. (2024). Development and strengthening of teachers' digital competence: Systematic review. *Contemporary Educational Technology*, 17 (1), <https://doi.org/10.30935/cedtech/15744>
- Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary issues in technology and teacher education*, 9(1), 60–70. <https://doi.org/10.1177/002205741319300303>.
- Kuranchie, A. (2021). *Research Made Easy* (3rd ed.). Bookworm Publications, Kumasi.
- Magbondé, K. G., Thiam, D., & Wagner, N. (2025). Impact of access to electricity on the well-being of rural households in Senegal. *Journal of Development Effectiveness*, 1–24. <https://doi.org/10.1080/19439342.2025.2499432>
- Marangu, P. K., Nyaga, F. G., & Rukaria, S. (2022). Overcoming Challenges Arising from Online Training in TVET Institutions in Kenya. Tenth Pan-Commonwealth Forum on Open Learning. <https://doi.org/10.56059/pcf10.9226>
- Muinda, P. E., Basaza-Ejiri, A. H., Maiga, G., & Mayoka, K. G. (2024). Evaluating a Digitization Model in Ugandan Technical and Vocational Education and Training (TVET) Institutions An Agency Theory Approach and Validation with Structured Walkthroughs. <https://doi.org/10.21203/rs.3.rs-4588350/v1>
- Nadapdap, E., Laili, E. F., Natsir, M., & Setyadi, M. C. S. (2025). Exploring the Influence of Digital Competence, Work-Life Balance, and Transformational Leadership on Teacher Productivity through Job Satisfaction in Rural Educational Contexts. *East African Scholars Journal of Economics, Business and Management*, 8(1), 44–55, <https://doi.org/10.36349/easjebm.2025.v08i01.006>
- Ogudo, P. A., Onyesom, A. E., Okeibunor, A., & Alabi, S. O. (2024). Availability and Utilization of Information and Communication Technology for the Teaching and Learning Business Education Programme. *Advances in Multidisciplinary and Scientific Research Journal*, 12(4), 23–32. <https://doi.org/10.22624/aims/bhi/v12n4p3>
- Pandey, P., & Pandey, M. M. (2015). *Research Methodology: Tools and Techniques*. Bridge Publisher, Los Angeles.
- Patton, M. Q. (2015). *Qualitative research & evaluation methods: Integrating theory and practice* (4th ed.). SAGE Publications.
- Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, 48(6),

1273–1296. <https://doi.org/10.1007/s11165-016-9602-2>

The Business & Financial Times. (2025, May 22). Digital divide widens: Only 2% deprived basic schools have functional ICT labs – Eduwatch report. Retrieved from <https://thebftonline.com/2025/05/22/digital-divide-widens-only-2-deprived-basic-schools-have-functional-ict-labs-eduwatch-report/>

UNESCO. (2025a, April 28). Closing the digital divide for women and girls in Africa through education. Retrieved from

<https://www.unesco.org/en/gender-equality/education/digital-divide>

UNESCO. (2025b, May 12). How girls shape tech on their own terms in Tanzania. Retrieved from

<https://www.unesco.org/en/articles/how-girls-shape-tech-their-own-terms-tanzania>

Wathi. (2023). Digitalisation of Education in Ghana: An Overview, November 2023. Retrieved from <https://www.wathi.org/situation-education-ghana-2024/digitalisation-of-education-in-ghana-an-overview-november-2023/>

Yu, Y., Appiah, D., Zulu, B., & Adu-Poku, K. A. (2024). Integrating Rural Development, Education, and Management: Challenges and Strategies. *Sustainability*, 16(15), 6474. <https://doi.org/10.3390/su16156474>

Zwart, D., Van Luit, J. E. H., Noroozi, O., & Goel, S. L. (2017). The Effects of Learning Material on Students' Mathematics Learning in Vocational Education. *Cogent Education*, 4(1), <https://doi.org/10.1080/2331186X.2017.1313581>

Impact Of E-Book Instructional Package On Junior Secondary School Students' Attitudes And Entrepreneurial Intentions In Business Studies In Ibadan Metropolis, Nigeria

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ABSTRACT:

This study investigated the effect of an E-Book instructional package on Junior Secondary School students' attitudes toward Business Studies (BS) and their entrepreneurial intentions in Ibadan Metropolis, Nigeria. Given the increasing importance of digital tools in education, the research aimed to determine whether integrating E-book instructional package could positively influence learners' attitude to business studies and stimulate their entrepreneurial intention. Specifically, the study assessed differences in attitudes and entrepreneurial intentions between students exposed to the E-Book package and those taught using conventional methods. Adopting a quasi-experimental pre-test-posttest control group design, two intact JSS II classes from public schools were selected, with one serving as the experimental group (n=40) and the other as the conventional group (n=40). The experimental group was taught using an interactive E-Book package, while the control group received traditional instruction. Data were collected using the Attitude toward Business Studies Scale (r=0.75) and the Entrepreneurial Intention Scale (r=0.70), and analyzed using descriptive statistics (mean and standard deviation) and inferential statistics (independent sample t-tests) to determine significant differences between groups. Results revealed significant improvements in both attitude ($t = 10.174$, $p < 0.05$) and entrepreneurial intention ($t = 10.261$, $p < 0.05$) among students taught with the E-Book instructional package compared to their counterparts in conventional group. The study underscores the potential of E-book instructional package to enhance students' engagement, attitude, and entrepreneurial mindset. This study therefore recommends the integration of E-book package into the BS curriculum to promote effective learning and prepare students for real-world economic participation.

KEYWORDS: E-Book Instructional Package, Business Studies, Junior Secondary School, Students' Attitude, Entrepreneurial Intention

1. Introduction

In today's rapidly evolving educational landscape, the integration of digital technologies into teaching and learning processes has gained global momentum. Educators, policymakers, and researchers alike are increasingly exploring innovative instructional strategies aimed at improving student engagement, enhancing understanding, and promoting meaningful learning outcomes. Among these innovations, the use of electronic books (E-Books) has emerged as a promising approach (Olalude et al., 2024). E-Books combine the benefits of traditional textbooks with the advantages of digital media, offering multimedia content, portability, interactivity, and instant access to a wide range of learning materials (Chau, 2018). These features not only support differentiated learning but also cater to the diverse needs and preferences of 21st-century learners. In developed countries, the implementation of E-Books in educational settings is becoming commonplace, with institutions leveraging digital content to enrich the learning experience. In developing nations like Nigeria, however, the adoption of such digital tools in the education sector remains relatively limited (Odawn, 2018). Despite the increasing availability of technology and internet access, many schools in Nigeria continue to rely heavily on traditional teaching methods, particularly in subjects such as Business Studies (Olalude et al., 2024). This gap in the integration of digital tools presents both a challenge and an opportunity for improving instructional delivery in the Nigerian context.

Business Studies, a core subject in the Junior Secondary School (JSS) curriculum in Nigeria, plays a vital role in introducing students to foundational concepts in business, finance, commerce, and entrepreneurship. Its primary objective is to equip students with basic business knowledge, practical skills, and an entrepreneurial mindset that can be harnessed in future educational and career pursuits. However, the subject is often delivered using teacher-centered approaches, including rote learning, textbook-based instruction, and limited practical engagement (Akpojtor, 2022). These traditional methods may not sufficiently stimulate students' interest or foster the entrepreneurial attitudes that the subject aims to develop. As a result, many students view Business Studies as theoretical, monotonous, or disconnected from real-life applications, which can negatively impact their attitudes toward the subject (Ogonu, 2019).

In this context, attitude refers to the inclination of junior secondary school students toward the concepts taught in business studies. This attitude can be positive, negative, or neutral, and the development of entrepreneurial intentions largely depends on having the right attitude. Students' perspectives on business studies significantly shape their outlook on entrepreneurship and whether they aspire to

become business owners or employees. Ogonu (2019) explains that students often form negative attitudes toward business studies because teachers rely heavily on traditional teaching methods that focus mainly on verbal instruction, with students playing a passive role. Such methods have been linked to limited stimulation of creativity, critical thinking, memory retention, and independent learning among students (Futterman, 2020; Ekoh, 2016). This challenge has contributed to a lack of entrepreneurial motivation, leading many students to depend on formal employment in public and private sectors, where job opportunities are increasingly scarce (Adeleye, 2017; Amesi & Giami, 2018). Supporting this view, Ibrahim et al., (2015) argue that many students' entrepreneurial ambitions are stifled due to the failure of teachers to use engaging and effective teaching strategies in business studies. This may be one of the reasons for the decline in students' interest in pursuing entrepreneurial paths. Hence, is a critical need to explore innovative instructional strategies that can enhance students' engagement, improve attitudes toward the subject, and inspire future entrepreneurial pursuits.

The use of an E-Book instructional package, which integrates multimedia content and interactive elements, may address these challenges by providing a more dynamic and engaging learning environment. This study therefore seeks to address these challenges by examining the impact of an E-Book instructional package on Junior Secondary School students' attitudes toward Business Studies and their entrepreneurial intentions in Ibadan Metropolis, Nigeria. The study is anchored on the belief that digital instructional tools such as E-Books, when effectively designed and implemented, have the potential to revolutionize classroom teaching. By incorporating interactive features, visuals, animations, quizzes, and real-world case studies, E-Books can make learning more engaging, relatable, and enjoyable for students. Such exposure can positively influence how students perceive Business Studies and may increase their motivation to explore entrepreneurship as a viable career path.

In light of the above, this study investigates the effectiveness of an E-Book instructional package in improving Junior Secondary School students' attitudes towards Business Studies and enhancing their entrepreneurial intentions in Ibadan Metropolis, Nigeria. The study is premised on the idea that innovative instructional materials like E-Books can make learning more engaging and relevant, thereby influencing students' perceptions and aspirations.

1.1 Aim and Objectives of the Study

The main objective of this study was to examine the impact of an E-Book instructional package on Junior Secondary School students' attitudes and entrepreneurial intentions in Business Studies. Specifically, the study aimed to:

- i. examine the effect of an E-Book instructional package on students' attitudes toward Business Studies.
- ii. determine the impact of the E-Book instructional package on students' entrepreneurial intentions.
- iii. compare the effectiveness of E-Book instructional delivery with traditional face-to-face instruction in Business Studies.

1.2 Research Hypotheses

Ho1: There is no significant difference in students' attitudes toward Business Studies between those taught using the E-Book instructional package and those taught using traditional methods.

Ho2: There is no significant difference in students' entrepreneurial intentions between those exposed to the E-Book instructional package and those in the control group.

2. Literature Review

2.1 Theoretical Framework: Cognitive Theory of Multimedia Learning by Mayer (2009)

This study is based on the Cognitive Theory of Multimedia Learning (CTML) proposed by Mayer (2009). The CTML emphasizes that learners strive to form meaningful links between words and images, resulting in deeper learning than when either words or images are used alone (Mayer, 2009). The theory suggests that a primary goal of multimedia instruction is to help learners develop a well-organized mental representation of the content being presented. In this process, learners actively engage with the material to make sense of it and, in doing so, construct new knowledge.

CTML outlines a model consisting of three types of memory: sensory memory, working memory, and long-term memory. According to Sweller (2017), sensory memory allows individuals to perceive new information, working memory is where conscious processing of information occurs, and long-term memory serves as the storage system for our accumulated knowledge. We only become aware of the information stored in long-term memory when it is retrieved and processed by working memory. The theory further explains that meaningful learning is most likely to happen when learners hold related visual and verbal information in their working memory at the same time. Instructional strategies that encourage this process

are more likely to result in meaningful learning. Therefore, the theory suggests that multimedia presentations, which combine words and images, are generally more effective for promoting meaningful learning than using only one medium.

2.2 E-Book Instructional Packages in Education

E-books have become an essential component of long-term teaching strategies for many educators. In addition to encouraging creativity, teachers view e-books as a practical alternative to traditional textbooks. Numerous research studies have highlighted effective teaching methods that incorporate e-book resources. For instance, Wells (2018), through a Delphi study involving experts in instructional technology and constructivism, found that online programs designed based on constructivist principles should be interactive, project-driven, and collaborative, while offering learners significant choice and control over their learning process.

Various experimental studies investigating the impact of interactive e-books on students' academic performance have demonstrated their positive influence on learning, skill development, and achievement. For example, Yee & Zainuddin (2018) found that e-books significantly improved the reading achievement of first-grade secondary school students. Similarly, Wells (2018) confirmed that self-directed learning through computers and e-books contributed to enhancing creative thinking among second-year science students at the Faculty of Education in Oman.

In another study, Alzaq (2018) found that different interactive e-book interfaces positively affected both academic achievement and skill performance among master's students in educational technology, as well as their attitudes towards the use of e-books. Additionally, Kumbhar (2018) demonstrated the effectiveness of e-books in helping kindergarten teachers develop multimedia presentation skills. These findings align with the results of Chau's study (2018). Nevertheless, research indicates that when appropriately implemented, e-books can lead to improved academic performance and digital literacy (Ogunlade *et al.*, 2022; Olalude *et al.*, 2024).

2.3 Attitudes Towards Business Studies

Students' attitudes towards a subject significantly influence their engagement, learning outcomes, and career preferences (Ogonu, 2019). Business Studies, a subject designed to introduce students to entrepreneurship, finance, and commerce, often struggles with poor perception among students due to its abstract nature and outdated teaching approaches (Ifeanyi *et al.*, 2018).

However, innovative teaching methods, including the use of digital tools, have been found to positively influence students' attitudes. According to Olalude (2023), the use of ICT in teaching Business Studies can make lessons more relatable and interactive, resulting in more favorable attitudes among learners. Moreover, when learners perceive Business Studies as practical and connected to real-life applica-

tions, they are more likely to develop a positive disposition towards it (*Afolabi et al., 2021*).

2.4 Entrepreneurial Intentions Among Secondary School Students

Entrepreneurial intention refers to the motivational factors that influence individuals to pursue entrepreneurial activities in the future (*Anwar et al., 2020*). In recent times, there has been a growing recognition of the importance of nurturing entrepreneurial mindsets at the secondary school level, particularly in developing countries where youth unemployment is high (*Brás et al., 2019*).

Business Studies plays a pivotal role in cultivating entrepreneurial awareness and intentions among students. However, its effectiveness depends on how engaging and practically oriented the instructional approach is. According to Amesi, et al., (2018), teaching entrepreneurship through interactive methods, such as case studies, simulations, and digital tools, helps students connect with entrepreneurial concepts more effectively

3 Research Methodology

This study adopted a quasi-experimental pretest-posttest control group design. The population comprised Junior Secondary School II (JSS II) students in public schools in Ibadan Metropolis, Nigeria. The subjects covered in the study were Trade, Market, and Channels of Distribution, as outlined in the Business Studies curriculum for junior secondary schools. The participants were students from Junior Secondary School II (JSS II) offering Business Studies. The selection of JSS II students was based on the fact that they had already completed one academic session in junior secondary school, during which they were introduced to both Business Studies and Computer Studies, and they were not yet preparing for any external examinations, unlike JSS III students.

Two public schools were purposively selected based on the following criteria; availability of computers to deliver the instruction, availability of alternative power supply in case of power outage, readiness and willingness of the school to participate in the study, availability of Business studies teachers and students in the schools. Each school provided an intact class of JSS II students i.e. E-book instructional package group (40) and Conventional group (40). One school was randomly assigned to the experimental group, and the other to the conventional group.

Two research instruments were used namely Attitude toward Business Studies Scale (ABSS) with the reliability coefficient of 0.75, and Entrepreneurial Intention Scale (EIS) with the reliability coefficient of 0.70.

The duration of the study was six weeks. In the first week, an introduction letter from the researcher's Head of Department was delivered to the selected schools. The second week was dedicated to training the research assistants who took part

in the study. During the third week, the pre-test was administered. The fourth to the sixth week were used for conducting the post-test. During this period, the experimental group was taught Business Studies using the E-Book instructional package, which included interactive texts, scenarios, animations, and self-assessment quizzes. The conventional group received the same content through traditional classroom lectures.

Pretest and posttest data were collected using the ABSS and EIS instruments. Data were analyzed using descriptive statistics (mean and standard deviation) and inferential statistics (independent sample t-tests) to determine significant differences between groups

4. Findings and Discussion

4.1 Descriptive Statistics

Table 1. Descriptive Statistics of Students' Attitude towards Business Studies and Entrepreneurial Intention (Pre-Test and Post-Test)

Variables of Interest	Descriptive Statistics			
	N	Minimum	Maximum	Mean ± S.E
Pre-Test on Student's Attitude towards Business Studies	80	41	72	56.45±0.72
Pre-test on student's entrepreneurial intention	80	40	74	55.80±0.73
Post-test on student's attitude towards Business Studies	80	46	85	64.71±1.04
Post-test on student's entrepreneurial intention		45	81	64.18±0.94

(Source: SPSS Output, 2025)

Table 1 presents the descriptive statistics showing the results of students' performance on attitude towards Business Studies and entrepreneurial intention before and after the intervention. The total number of participants for each measure was 80.

4.1.1 Pre-Test on Students' Attitude towards Business Studies

The pre-test assessed students' initial attitude towards Business Studies. The scores ranged from a minimum of 41 to a maximum of 72, with a mean score of 56.45 and a standard error (S.E) of ± 0.72 . This result provides a baseline understanding of students' attitudes before they were exposed to the intervention. The relatively moderate mean score suggests that students had a fair but not particularly high positive attitude towards Business Studies at the outset.

4.1.2 Pre-Test on Students' Entrepreneurial Intention

Similarly, the pre-test for entrepreneurial intention measured students' initial desire, intention, or motivation to pursue entrepreneurial activities. The scores ranged from 40 to 74, with a mean score of 55.80 and a standard error of ± 0.73 . This indicates that students' entrepreneurial intention was moderate prior to the intervention, suggesting room for improvement.

4.1.3 Post-Test on Students' Attitude towards Business Studies

After the intervention, students' attitudes were re-assessed. The post-test scores showed an increase, ranging from 46 to 85, with a mean score of 64.71 and a standard error of ± 1.04 . The increase in the mean score compared to the pre-test (from 56.45 to 64.71) suggests a positive impact of the intervention on students' attitudes towards Business Studies. The higher maximum score and increased mean imply that students developed a more favorable perception and attitude towards the subject after the intervention.

4.1.4 Post-Test on Students' Entrepreneurial Intention

The post-test scores for entrepreneurial intention also reflected an improvement, with scores ranging from 45 to 81, and a mean score of 64.18 with a standard error of ± 0.94 . The mean score increased from 55.80 (pre-test) to 64.18 (post-test), demonstrating that students showed higher entrepreneurial intention following the intervention.

4.2 Inferential Analysis

The analysis was used to test the hypotheses using Paired Sample T-test

Ho1: There is no significant difference in students' attitudes toward Business Studies between those taught using the E-Book instructional package and those taught using traditional methods.

Table 2. T-test summary of mean differences in students' attitudes toward Business Studies between E-Book instructional package and conventional methods.

Treatment	N	Mean	SD	DF	Tcal	Sig	Cohen-D
E-books	40	71.73	6.33	78	10.174	0.000	2.27
Conventional package	40	57.70	6.00				

The result from Table 2 revealed a statistically significant difference in students' attitudes toward Business Studies between those exposed to the E-Book instructional package and those taught using conventional methods ($t = 10.174$, $p < 0.05$ level of significance). Students taught using the E-Book instructional package (Mean = 71.73) had a more positive attitude compared to those taught using traditional methods (Mean = 57.70), indicating that the E-Book instructional package positively influenced students' attitudes. which means we reject the null hypothesis one. The effect size, measured by Cohen's d was 2.27, indicating a very large effect.

Ho2: There is no significant difference in students' entrepreneurial intentions between those exposed to the E-Book instructional package and those in the control group.

Table 3. T-test summary of mean differences in entrepreneurial intentions toward Business Studies between E-Book instructional package and conventional methods

Treatment	N	Mean	SD	DF	Tcal	Sig	Cohen-D
E-books	40	70.48	5.17	78	10.261	0.000	2.29
Conventional package	40	57.88	5.80				

(Source: SPSS Output, 2025)

The result from Table 3 revealed a statistically significant difference in students' entrepreneurial intentions between those exposed to the E-Book instructional package and those taught using conventional methods ($t = 10.261$, $p < 0.05$ level of significance). Students taught using the E-Book instructional package (Mean = 70.48) showed higher entrepreneurial intention compared to those taught using conventional methods (Mean = 57.88), indicating that the E-Book instructional package positively influenced students' entrepreneurial intention, which means we reject the null hypothesis two. Additionally, the Cohen's d result of 2.29 indicates that the effect size is a very large.

5.0 Discussion of the Findings

Mean differences in students' attitudes toward business studies between E-Book instructional package and conventional methods

The finding revealed a significantly difference in the students' attitudes toward Business studies between E-book instructional package and conventional methods. This suggests that the use of E-Books can positively influence students' attitudes toward learning Business Studies. The interactive, multimedia-rich nature of E-Books may have made the learning experience more engaging and enjoyable for students, thereby improving their perception of the subject. This result aligns with the findings of Odawn (2018) that emphasizes the motivational advantages of E-book instructional package, which can cater to different learning styles and enhance student engagement. These findings also support Olalude (2023) argument that the use of ICT in teaching Business Studies can enrich and make lessons more relatable and interactive, resulting in more favorable attitudes among learners. Moreover, when learners perceive Business Studies as practical and connected to real-life applications, they are more likely to develop a positive disposition towards it.

5.1 Mean differences in entrepreneurial intentions toward Business Studies between E-Book instructional package and conventional methods

The finding revealed that the E-Book instructional approach not only improved students' understanding of Business Studies but also inspired stronger entrepreneurial aspirations. This could be attributed to the dynamic content in the E-Book package, which may have included real-world business scenarios, interactive exercises, or success stories that encouraged students to envision themselves as future entrepreneurs. This supports Amesi et al., (2018); Olalude (2023) studies that stress the importance of innovative and relevant instructional materials in promoting entrepreneurial thinking among students. By incorporating interactive features, visuals, animations, quizzes, and real-world case studies, E-Books can make learning more engaging, relatable, and enjoyable for students. Such exposure can positively influence how students perceive Business Studies and may increase their motivation to explore entrepreneurship as a viable career path.

In summary, the results from both hypotheses clearly demonstrate that the E-Book instructional package was more effective than traditional teaching methods in enhancing both students' attitudes and entrepreneurial intentions in Business Studies. These outcomes underscore the potential of integrating technology into classroom instruction to make learning more impactful, especially in subjects that are skill- and application-oriented like Business Studies.

Based on the findings of this study, the following recommendations were made;

- i. Schools should incorporate E-Book instructional packages into the teaching of Business Studies to make lessons more engaging and relevant to the students.
- ii. Curriculum planners and instructional designers should develop and distribute quality digital resources tailored to the Nigerian educational context.
- iii. Government and educational stakeholders should invest in ICT infrastructure to support the widespread adoption of digital learning tools.

6.0 Conclusion and Further Research

This study concludes that the use of an E-Book instructional package significantly improves Junior Secondary School students' attitudes toward Business Studies and enhances their entrepreneurial intentions. The interactive and engaging nature of the E-Book made the subject more interesting and relevant to students, thereby promoting deeper learning and fostering entrepreneurial thinking. These results align with existing research indicating that technology-enhanced instruction can improve student engagement, motivation, and academic achievement. In

particular, the study contributes to the growing body of evidence supporting the integration of e-learning resources most especially in Nigerian classrooms.

During the course of this study, several new possibilities for expanding the research emerged. Firstly, the positive impact of the E-Book instructional package on students' attitudes and entrepreneurial intentions revealed the potential for integrating digital learning tools more extensively across different subjects beyond Business Studies. This suggests that similar interventions could be explored in other areas of the Junior Secondary School curriculum, such as Mathematics, Science, and Civic Education, to examine whether interactive E-Books can foster improved learning outcomes and positive dispositions in these subjects. Secondly, while the study focused on students' entrepreneurial intentions, the findings opened up opportunities for future research to investigate whether these intentions translate into actual entrepreneurial skills and behaviors over time. Longitudinal studies could be designed to track students beyond the six-week intervention to assess the sustainability of the observed changes and their real-world application.

Additionally, the study was limited to only two public schools in Ibadan Metropolis with basic ICT infrastructure. However, the results suggest the possibility of expanding the research to include a more diverse and larger population, including rural schools, private schools, and institutions in other regions of Nigeria. This would provide a broader understanding of the effectiveness of E-Book instructional packages across different contexts and resource levels. Furthermore, the use of self-reported measures highlighted the need for mixed-method research. Future studies could incorporate qualitative approaches such as interviews or focus group discussions to gain deeper insights into students' experiences, challenges, and perceptions regarding digital instructional tools.

Finally, the successful implementation of the E-Book package in this study underscores the potential for developing more localized, culturally relevant, and context-specific digital instructional resources. This opens the door for collaboration between curriculum planners, instructional designers, and technology developers to create comprehensive digital solutions tailored to the Nigerian educational system.

7.0 References

- Adeleye, O. J. (2017). 'Pedagogical challenges on the effectiveness of business studies teachers in junior secondary schools', Oyo state', *International Journal of Advanced Academic Research Arts, Humanities and Education*, 3(3), 32-45.
- Adigun, J. O., & Yusuf, M. O. (2019). 'Effect of e-book instructional package on students' achievement in selected concepts in computer studies in Kwara State, Nigeria', *International Journal of Education and Research*, 7(2), 123-134.
- Afolabi, A. O., & Loto, A. B. (2021). 'Entrepreneurship education in Nigerian secondary schools: Challenges and prospects', *Journal of Educational and Social Research*, 11(1), 143-150. <https://doi.org/10.36941/jesr-2021-0013>
- Akpojtör, B. E. (2022). 'Difficulties confronting students in the acquisition of practical skills in business education in tertiary institutions in Delta State', *ABTU Journal of Science, Technology and Education*, 10(1), 99-104.
- Alzaq, E. S. (2018). The effect of differing interaction interface in the e-book on cognitive achievement and skills performance among students of educational technology and attitudes towards it. *Journal of Psychiatric and Educational Research*, 23.2: 104-141.
- Amesi, J., & Giami, D. K. (2018). 'Challenges hindering the availability of instructional resources for entrepreneurial skills acquisition among business education students in tertiary institutions, Rivers State', *International Journal of Education and Evaluation*, 4(1), 22-27.
- Anwar, Imran, Imran S., Baharul I., Prabha T., and Rizwan K. (2020). 'Entrepreneurial intention among female university students: Examining the moderating role of entrepreneurial education', *Journal for International Business and Entrepreneurship Development* 12(1) 217-34.
- Ayanlade, A., & Adepoju, K. A. (2020). 'Digital technology and classroom instruction in Nigeria: Trends, challenges and prospects', *Journal of Educational Technology Systems*, 49(1), 56-73. <https://doi.org/10.1177/0047239520919782>
- Brás, Gonçalo R., and Elias S. (2019). 'The determinants of entrepreneurship at the country level: A panel data approach', *Entrepreneurship Research Journal* 9: 1-17.

Chau, M. (2018). The effects of electronic books designed for children in education: Essays on the design of electronic text (SCROLL), 1(1), 20-25.

Ekoh, A. C. (2016). 'Traditional pedagogy to innovative pedagogy in business education. A challenge to business education', Nigerian Journal of Business Education 3(2), 126-136.

Federal Republic of Nigeria. (2014). National Policy on Education (6th ed.). NERDC Press, Nigeria

Futterman, M. (2020). 'Organizing instruction and study to improve students' learning'. Washington DC: National Center for Education Research, International Journal of Economics Education Research, 4(1), 35-38.

Ibrahim, W. N. A., Bakar, A. R., Asimiran, S., MOhamed, S., & Zakaria, N. S. (2015). 'Impact of entrepreneurship education on the entrepreneurial intentions of students in technical and vocational education and training institutions (TVET) in Malaysia', International Journal of Education Studies, 8(12), 141-156. <https://doi.org/10.5539/ies.v8n12p141>

Ifeanyi, I. P., & Chukwuere, J. E. (2018). 'The impact of the use of electronic books (E-books) on student learning in higher education institutions', Journal of Communication, 9(2), 151-160.

Kumbhar, R. (2018). Trends in e-book research. Journal of Library and Information Technology, 38.3: 162-169. Doi: 10.14429/djlit.38.3.12382

Mayer, R. E. (2009). Multimedia learning. Second Edition. New York, Cambridge University Press.

Odawn, T. (2018). 'Effect of E-book and Printed text on Students' learning Outcome in English in Kwara State', Unpublished Ph.D. thesis, University of Ibadan, 45-49.

Ogonu, O. G. (2019). 'Challenges of the use of new technologies in the teaching of business education courses in tertiary institutions in Rivers State, Nigeria', Nigerian Journal of Business Education, 6(1), 318-330.

Ogunlade, O. O., & Adebayo, B. I. (2022). 'Integrating digital tools in teaching business education in Nigerian secondary schools: A pathway to entrepreneurship development', Nigerian Journal of Business Education, 9(1), 88-96.

Okeji, C. C., Nwankwo, N. G., Anene, I. A. and Olorunfemi E. A. (2020). 'Assessment of digital literacy skills of 21st century librarians in private university libraries in Anambra State', International Journal of Library and Information Science Studies, 6(4), 34-47.

Okonkwo, C. A., & Adegbiya, M. V. (2020). 'Teachers' perception of the use of e-books in Nigerian secondary schools: Challenges and opportunities', International Journal of Educational Development Using ICT, 16(3), 72-85.

Olalude, O. O. (2023). 'Development and efficacy of infographics and e-book instructional packages in business studies among junior secondary school students in Ibadan', Nigeria. Unpublished Ph.D. thesis, University of Ibadan, 9-12.

Olalude, O.O., Aremu, A., & Olasunkanmi, I.A. (2024). 'Effect of infographics and e-book instructional packages on junior secondary school students' learning outcomes in Business Studies in Ibadan, Nigeria', *FNAS Journal of Computing and Applications*, 2(1), 105-113.

Olatunbosun, H. O. (2020). 'Promoting entrepreneurship education in Nigerian secondary schools: The role of innovative instructional strategies', *African Journal of Educational Research and Development*, 13(1), 112-124.

Shelburne, W.A. (2019). 'E-book usage in an academic library: User attitudes and behaviors', *Library Collections, Acquisitions and Technical Services*, *IJEBP*, 6(2), 59-72. <https://doi.org/10.1080/14649055.2009.10766234>.

Sweller, J. (2017). Without an understanding of human cognitive architecture, instruction is blind. The ACE Conference. Retrieved from <https://youtube/gOLPf9Ls-w..3rd June, 2020>.

Wells, C. L. (2018). Do students using electronic books display different reading comprehension and motivation levels than students using traditional print books? Unpublished Ph.D Thesis, Liberty University, Lynchburg, VA, 12-20.

World Bank. (2020). Digital technologies in education: Opportunities and challenges in developing countries, World Bank Publications.

Yee, B. C. & Zainuddin, N. S. (2018). The use of E-book to improve Reading Comprehension among Year Four Pupils. *J. Engl. Educ.* 4.3:23-32. doi: 10.31327/jee.v3i1.477.

Bridging The Digital Divide: Challenges And Lessons From Piloting An Asynchronous Stem Teacher Training In Ghana

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ABSTRACT:

The study sought to gather insights from Practical Education Network's (PEN) asynchronous online training organized in October 2024 for basic school teachers who handle Mathematics and Science. The training aimed to identify the enablers and the barriers of online training to improve future online training delivery. A mixed-methods approach was used, analysing data from pre-training and post-training surveys to gather both qualitative and quantitative insights. The trainer and participants' reflections also provided some qualitative insights for this study. Although many teachers appreciated the flexibility of asynchronous learning, only 23% of those who attended the onboarding session completed the training. The low completion rate was primarily linked to difficulty in navigating the Learning Management System (LMS), inadequate orientation, and limited support for participating teachers. Notably, all participants who completed the training attended the onboarding session. This highlights onboarding as central to the persistence of participants in the online learning environment. Piloting a fully asynchronous model in a low-resource African setting presents both unique challenges and critical insights for digital education stakeholders. The study highlights three key contributions: reveals the centrality of onboarding sessions, underscores the importance of stakeholder reinforcement in sustaining engagement, and proposes a hybrid model that blends both asynchronous content with personalised support. These findings project new possibilities for scalable, inclusive teacher professional development in contexts where connectivity and infrastructure remain uneven.

KEYWORDS: Asynchronous Training, STEM Education, Teacher Engagement, LMS Usability, Professional Development, Learner Support.

1. Introduction

The integration of digital technologies into professional development programs for teachers has become increasingly important, particularly in low-resource educational settings where access to continuous training remains a persistent challenge (Napitupulu et al., 2024). Online asynchronous training, hailed for its flexibility and scalability, promises to make professional learning across wide geographies more democratic and inclusive (Burns, 2023). Despite its potential, this model has its limitations that can hinder sustained engagement and deep learning. In Ghana, where infrastructure and digital literacy levels vary widely, designing effective online teacher development initiatives calls for more than good content; it demands intentional structures that support, motivate, and meaningfully connect educators to the learning process.

In response to these challenges, Practical Education Network (PEN) embarked on a fully asynchronous online training programme for Mathematics and Science teachers in October 2024. This initiative was built upon a prior online teacher training pilot conducted in 2020–2021 during the COVID-19 pandemic, which had successfully combined asynchronous modules with synchronous support. The 2024 training aimed to increase accessibility and educator autonomy by minimizing real-time interaction and instead relying on pre-designed digital content, learning management systems, and remote feedback.

What differentiates the Ghanaian case is the context-specific adaptation and innovation required to support teachers in a fully asynchronous model. With limited digital literacy and infrastructure, PEN's use of familiar technologies like WhatsApp for assignment submissions illustrates the necessary responsiveness to local realities. Yet, the absence of real-time support and stakeholder involvement led to a steep dropout rate, revealing the tension between flexibility and engagement in low-resource environments.

This study investigates the barriers and enablers of teacher persistence in fully asynchronous online training programmes. Specifically, the research aims to (1) identify factors contributing to low completion rates in PEN's 2024 training, (2) compare outcomes with the earlier 2020–2021 blended training model, and (3) offer context-responsive design recommendations for future online training. The objective of this study is to inform scalable training models that uphold both reach and quality across different teacher populations.

2.Contextualising Asynchronous Online Teacher Training

The advent and improvement of distance education have transformed professional development across sectors, with teacher education emerging as one of the primary beneficiaries (burns, 2023). Globally, online learning is now the dominant mode of distance education, driven by increased internet access and the adaptability of digital tools (culduz, 2024; burns, 2023). For many low and middle-income countries, online teacher training offers a promising path to equitably scaling teacher professional development, especially in hard-to-reach communities (hennesy et al, 2015).

The rise of asynchronous models where learning occurs at different times and locations presents a double-edged sword (Varkey et al., 2022). While asynchronous learning affords teachers flexibility and self-paced engagement, it also imposes significant burdens of self-regulation and digital literacy (Varkey et al., 2022). Research suggests that without sufficient scaffolds, learners often struggle to persist and complete asynchronous courses (Sharma & Hannafin, 2004). This reality is echoed in Massive Open Online Courses (MOOCs), where completion rates typically range from 2% to 14% despite high enrolment figures (Jordan, 2015; Billsberry & Alony, 2023).

Within Sub-Saharan Africa, these challenges are compounded by infrastructural and socio-cultural constraints. Teachers often lack stable internet, adequate digital tools, and prior exposure to Learning Management Systems (LMS) (Mukuni, 2019; Joshi & Khatiwada, 2024). Furthermore, women who form the majority of the teaching workforce face greater barriers to accessing online training due to systemic gender inequalities (International Telecommunication Union, 2022). Asynchronous training in these contexts risks becoming disengaged content delivery, rather than transformative professional learning (Cabral & Fuller, 2023).

Research on teacher persistence in online training highlights the significance of early engagement, personalised support, and stakeholder reinforcement (Hanson & Beem, 2022). Studies show that onboarding serves as a necessity. Participants who attend orientation sessions are more likely to complete training, especially when local education authorities or institutional partners reinforce attendance (Hanson & Beem, 2022).

Moreover, asynchronous learning must be designed with a blend of interactivity, motivation, and adaptability to meet diverse learner needs (Saluky & Bahiyah, 2023). Studies recommend blending asynchronous courses with periodic live sessions (where participants are engaged through video and audio platforms in real time), one-on-one coaching, and the use of familiar technologies such as WhatsApp or SMS to enhance accessibility and reduce content overload (Moorhouse & Wong, 2021).

Finally, recent reviews emphasize the need for humanising digital pedagogies in asynchronous teacher training. When educators feel seen, supported, and guided even at a distance, they are more likely to engage, apply their learning, and transform their classroom practices (Mehta & Aguilera, 2020). This underscores the argument that online learning, especially in low-resource environments, must be socially embedded, relationally anchored, and pedagogically intentional.

3. Research Methodology

This study employed a mixed-methods design, combining quantitative tracking with qualitative insights to explore teacher persistence in PEN's asynchronous on-line training. This approach enabled the researchers to examine measurable outcomes while capturing participant experiences in context (Creswell & Plano Clark, 2018).

3.1 Research design and participants

The research followed an explanatory sequential design, where quantitative data (e.g., subscription and completion rates) guided the analysis of qualitative data, including participant reflections and open-ended survey responses (Tashakkori & Teddlie, 2010).

The study targeted in-service Mathematics and Science teachers interested in continuous professional development through virtual platforms. Participants were recruited through an open call published on PEN's website and social media platforms. Ultimately, 162 teachers subscribed to the training, representing a diverse pool from Ghana and other African countries, as well as one from Belize.

3.2 Data Collection Tools

Quantitative data were derived from registration records, onboarding attendance, and assignment submissions. Qualitative data included responses from pre-training and post-training surveys, feedback forms, and messages shared via WhatsApp support groups.

To enhance transparency, sample survey items and feedback prompts have been included in the Appendix.

3.3 Data Analysis

Quantitative data were analysed using descriptive statistics (frequencies and percentages) to determine participation and completion patterns. These data were also compared to the 2020–2021 blended pilot to assess trends in persistence.

For qualitative data, responses were analysed through thematic coding, using manual methods to identify recurring patterns around barriers, motivations, and user experiences. Codes were refined iteratively and reviewed by the researchers to ensure consistency and reduce bias. Reliability was maintained through discussion.

4. Findings and Discussion

PEN's 2024 asynchronous online training initiative reflects broader patterns in the literature on teacher professional development in low-resource settings. This section presents findings on participation trends, key barriers and enablers, and contextual factors influencing teacher persistence. Where relevant, comparisons are drawn with the earlier 2020 - 2021 blended training model.

4.1 Participant Overview

A total of 162 teachers enrolled in the training, predominantly in-service Mathematics and Science teachers across primary and secondary levels. Gender distribution was approximately 36% female and 64% male. While most participants were based in Ghana, others joined from Liberia, Nigeria, and one from Belize.

"I was excited to try something new. But after onboarding, I didn't know how to continue... I needed someone to guide me." - Ghanaian Math teacher.

Table 1. Participant Demographics

Attribute	Category	Frequency	Total
Gender	Female	59	162
	Male	103	
Location	Ghana	153	162
	Other African Countries	8	
	Belize, USA	1	
Teaching Level	Basic (Primary/JHS)	139	162
	SHS	23	

4.2 Persistence and platform engagement

Out of the 162 who subscribed, only 31 attended the onboarding session, and 7 completed the full course. This indicates a completion rate of 4.3%, consistent with global MOOC trends (Jordan, 2015). The steep attrition mirrored patterns seen in other asynchronous models lacking real-time support (Sharma & Hannafin, 2004).

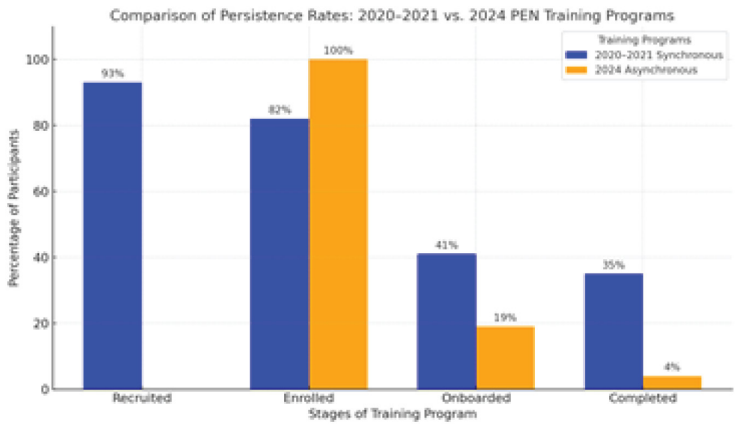


Figure 1. Comparison of persistence rates between 2020/21 and 2024 training programs (Source: Hanson & Beem, 2022)

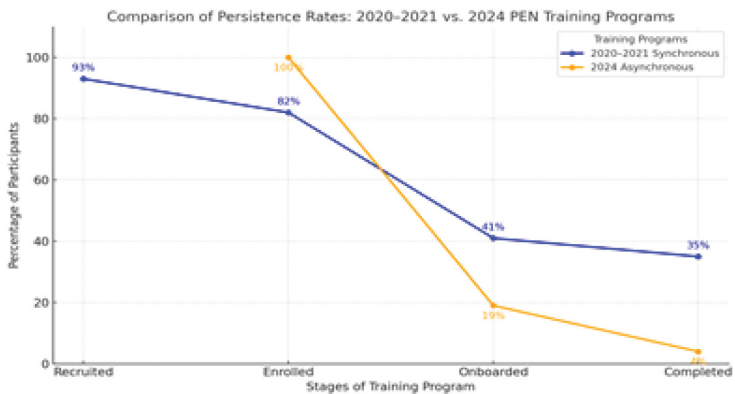


Figure 2. Comparison of Completion Rates – 2020/21 Blended vs. 2024 Asynchronous (Source: Hanson & Beem, 2022)

Participants highlighted difficulty navigating the LMS, lack of timely feedback, and Absence of regular communication as some of the reasons for disengaging.

"I didn't even know if my assignment had been received. There was no confirmation or feedback." – Liberian Science teacher

4.3 Onboarding and early engagement

The data reinforces existing research on the importance of onboarding. The stark drop-off before or immediately after onboarding affirms that orientation is not just a technical requirement, but a crucial emotional and instructional bridge (Hanson & Beem, 2022).

In contrast, the 2020/21 model included district-facilitated onboarding with support from education directors a strong motivator for persistence.

"In 2021, my director encouraged us. This time, I felt alone." - Ghanaian Math teacher.

4.4 Digital infrastructure challenges

Many participants faced connectivity issues, unstable devices, and unfamiliar LMS features. PEN's decision to accept WhatsApp submissions and send reminder messages via WhatsApp and e-mails offered a workaround that is grounded in local digital familiarity.

"I could not upload the file on Google Classroom, but I sent it on WhatsApp, and that saved me." – Ghanaian Science teacher.

This adaptation echoes Moorhouse & Wong's (2021) recommendation to leverage familiar platforms in low-resource settings to support engagement.

4.5 Content and curriculum misalignment

Teachers found the activities of the training engaging but not always well-aligned with their local curriculum or teaching grade.

For example, *"The activity with chemical reactions was interesting, but I teach grade 4. I wasn't sure how to connect it."*- Ghanaian Science teacher

This underscores the need to tailor training materials not only to the subject area, but also to grade level and curricular objectives. Providing a mapping guide to curriculum strands or adapting activity versions per level would enhance usability.

4.6 Contributions to the Field

This study affirms existing barriers but also extends the conversation by offering new insights from a fully asynchronous pilot in sub-Saharan Africa. The study found that onboarding is foundational and not a procedural step. Also, platform familiarity and flexible support channels (e.g., WhatsApp) increase accessibility. Finally, training content must be pedagogically localized, aligning with curriculum and grade-level needs.

"I liked the training, but I didn't know how to use it in my class. Maybe next time, have examples for KG, upper primary, etc."- Ghanaian Math and Science teacher.

4.7 Recommendations

Based on the literature and findings of this study, there is a need to integrate live onboarding as an entry point for the training. This will help orient participants on the need for the training, its expectations, and also respond to some questions they may have, even before they begin the training. Additionally, participants should have multiple pathways for submitting assignments. This will ensure that, in the event that any participant has challenges in accessing a given platform, they can easily switch to one that is more convenient.

While flexibility is often cited as a benefit of asynchronous models (Burns, 2023), PEN's experience illustrates its limitations in the absence of structured interaction. Many teachers disengaged when they did not receive prompts or guidance.

By contrast, in the blended model, periodic virtual check-ins helped sustain motivation. PEN's 2024 model shows that asynchronous success requires strategic social connection, even if not in real-time.

Moreover, there is a need to adapt the contents of the training to the specific needs of the participants. Where training contents are not adapted to the needs of the participants, there may be a high possibility of drop out and disengagement. Institutionalization of weekly check-ins through SMS, WhatsApp, or short calls with the participants may get them connected, serve as some level of motivation, and increase the persistence of participants.

Finally, to preserve the flexibility offered by self-paced training whilst still upholding strategic interaction, there will be a need to blend both synchronous elements and asynchronous elements in future training programs.

5. Conclusion and Further Research

This paper examined the design and implementation of a fully asynchronous online training programme developed and implemented by the Practical Education Network (PEN) for science and mathematics teachers across Africa. The initiative emerged from a growing need to deliver scalable, flexible, and contextually relevant professional development to teachers working in diverse, often resource-constrained environments. By focusing on PEN's 2024 asynchronous model and comparing it with an earlier blended pilot, the findings uncovered critical insights on what supports or hinders teacher persistence in such training formats.

The findings revealed that asynchronous learning is promising in terms of reach and convenience for participants. However, it requires more than the content to be effective. Participants' engagement in using these online platforms is shaped by access to familiar technologies, clarity of the content and its alignment with the approved curriculum, availability of timely feedback to participants' queries and submissions, and the presence of institutional support. When these were lacking, participation dropped significantly. This study highlights the importance of intentional onboarding, human connection, and adaptable delivery in designing digital professional development programmes for African educators.

These findings are especially relevant to educational ministries, NGOs, and regional training providers working to expand teacher learning across the continent. The study offers practical design considerations for those seeking to reach wider audiences while ensuring that engagement, relevance, and impact are not compromised.

Future studies may explore how integrating AI-powered chat support or automated feedback tools could simulate human presence and reduce participant isolation in asynchronous environments. Comparative studies across countries could reveal how cultural, linguistic, or policy differences influence participation and outcomes in pan-African training programmes. Lastly, tracking the long-term classroom application of training content would provide essential data on whether asynchronous learning in any way leads to improved teaching practices and learner experiences.

6. Acknowledgement

We appreciate the PEN team for working hard to implement this asynchronous teacher training. Our appreciation also goes to all the teachers who signed up for this training and especially to those who persisted to complete the training.

7. References

- Billsberry, J. & Alony, I. (2023), 'The MOOC Post-Mortem: Bibliometric and Systematic Analyses of Research on Massive Open Online Courses (MOOCs), 2009 to 2022', *Journal of Management Education*, Vol. 48. <https://doi.org/10.1177/10525629231190840>
- Burns, M. (2023), *Distance Education for Teacher Training: Modes, Models, and Methods*, 2nd ed., Washington, DC: Education Development Center.
- Cabral, A. & Fuller, S. (2023), 'Key Factors for Designing and Delivering an Effective Asynchronous Professional Learning Experience', *Compass: Journal of Learning and Teaching*, Vol. 16, pp. 117–143. <https://doi.org/10.21100/compass.v16i1.1392>
- Creswell, J.W. & Plano Clark, V.L. (2018), *Designing and Conducting Mixed Methods Research*, 3rd ed., Thousand Oaks, CA: Sage.
- Culdaz, M. (2024), 'Benefits and Challenges of E-Learning, Online Education, and Distance Learning', <https://doi.org/10.4018/979-8-3693-4131-5.ch001>
- Hanson, M. & Beem, H. (2022), 'Role of Digital Literacy and Tools in Teacher Persistence in an Online Hands-On Science Training in Ghana', *Proceedings of the 2022 WEEF-GEDC Conference*, pp. 1–5. <https://doi.org/10.1109/WEEF-GEDC54384.2022.9996262>
- Hennessy, S., Haßler, B. & Hofmann, R. (2015), 'Challenges and Opportunities for Teacher Professional Development in Interactive Use of Technology in African Schools', *Technology, Pedagogy and Education*. <https://doi.org/10.1080/1475939X.2015.1092466>
- International Telecommunication Union (ITU). (2023), 'Bridging the Gender Divide', [online] Available at: <https://www.itu.int/en/mediacentre/backgrounders/Pages/bridging-the-gender-divide.aspx> [Accessed 27 May 2025].
- Jordan, K. (2015), 'Massive Open Online Course Completion Rates Revisited: Assessment, Length and Attrition', <https://doi.org/10.13140/RG.2.1.2119.6963>
- Joshi, B. & Khatiwada, S. (2024), 'Analyzing Barriers to ICT Integration in Education: A Systematic Review', *The Third Pole: Journal of Geography Education*, Vol. 24, pp. 25–45. <https://doi.org/10.3126/tp.v24i1.73325>

Moorhouse, B. & Wong, K. (2021), 'Blending Asynchronous and Synchronous Digital Technologies and Instructional Approaches to Facilitate Remote Learning', *Journal of Computers in Education*, Vol. 9. <https://doi.org/10.1007/s40692-021-00195-8>

Mukuni, J. (2019), 'Challenges of Educational Digital Infrastructure in Africa: A Tale of Hope and Disillusionment', *Journal of African Studies and Development*, Vol. 11, pp. 59–63. <https://doi.org/10.5897/JASD2019.0539>

Napitupulu, M., Muddin, A., Bagiya, B., Diana, S. & Rosyidah, N. (2024), 'Teacher Professional Development in the Digital Age: Strategies for Integrating Technology and Pedagogy', *Global International Journal of Innovative Research*, Vol. 2, pp. 2382–2396. <https://doi.org/10.59613/global.v2i10.334>

Saluky, S. & Bahiyah, N. (2023), 'Revolutionizing Education: Unlocking the Potential of Asynchronous Video for Interactive Online Learning', *International Journal of Education and Humanities*, Vol. 3, pp. 187–196. [https://doi.org/10.58557/\(ijeh\).v3i2.149](https://doi.org/10.58557/(ijeh).v3i2.149)

Sharma, P. & Hannafin, M. (2004), 'Scaffolding Critical Thinking in an Online Course: An Exploratory Study', *Journal of Educational Computing Research*, Vol. 31, pp. 181–208. <https://doi.org/10.2190/TMC3-RXPE-75MY-31YG>

Varkey, T., Varkey, J., Ding, J., Varkey, P., Zeitler, C., Nguyen, A., Merhavy, Z. & Thomas, C. (2022), 'Asynchronous Learning: A General Review of Best Practices for the 21st Century Asynchronous Learning', *Journal of Research in Innovative Teaching & Learning*, Vol. 16, pp. 4–16. <https://doi.org/10.1108/JRIT-06-2022-0036>

8. Appendices

Appendix A: Thematic Analysis of Participant Follow-up Calls

To deepen understanding of low course completion, PEN conducted follow-up calls with participants. Below is a summary of common themes and illustrative excerpts drawn from the responses.

Common Challenges Identified

Theme	Description	Example/Quote
Over commitment	Teachers subscribed to multiple online trainings and couldn't keep up.	<i>"I subscribed to several training programmes... mostly I forget that I have subscribed."</i>
Forgetfulness / No Reminders	Participants often forgot about the training, especially without reminders.	<i>"I didn't get any reminder and I forgot about the training."</i>
Poor Network Access	Some teachers, especially in remote areas, faced severe connectivity issues.	<i>"My station is in a remote area... I have serious challenges with network."</i>
Device/Tech Constraints	Broken smartphones, laptops, or platform navigation issues limited access.	<i>"I had challenges with my phone and I am no longer using a smartphone."</i>
Personal Emergencies	Bereavement, family issues, or school schedules delayed engagement.	<i>"Has been bereaved and needs time to return to training."</i>
Platform Confusion	Several participants got confused using Google Classroom or accessing resources.	<i>"I had challenges navigating Google Classroom. I got lost often."</i>
Recognition as Motivation	NTC Accreditation motivated some to reconsider completing the training.	<i>"I will go back and complete it since it is NTC Accredited."</i>

Appendix B: Some sample questions on the pre-survey and post-survey forms

Pre-Training Survey Items

- How confident are you in using online learning platforms (e.g., Google Classroom)? Very confident/ Somewhat confident/ Not confident at all
- Which device do you plan to use for this training? Smartphone/ Laptop/ Tablet
- How reliable is your internet connection for participating in this training? Always available/ Occasionally available/ Rarely available/ Not available
- Why are you interested in joining this training? (Open-ended)
- Do you expect the training content to match your classroom needs and curriculum level? Yes / No/ To a very large extent

Post-Training Survey sample items

- Did you complete all required modules in the training? Yes / No / Partially
- How easy was it to navigate the Learning Management System (LMS)? Very easy/ Moderately easy/ Difficult/Very difficult
- Did you receive timely support when you had challenges? Yes/No/I didn't need support
- To what extent did the training content align with your teaching grade or subject area? Very well/Somewhat/Not at all
- Do you feel confident applying what you learned in your classroom? Yes/Not sure/ No
- What would improve your experience in future online teacher trainings? (Open-ended)

Appendix C: Feedback Questions for Onboarding Session

- How would you rate today's onboarding session? (1=very poor, 5=excellent)
- How easy was it to understand the facilitator? (1=not easy to understand at all, 5=very easy to understand)
- How clear are you about the way to navigate through and complete the online training? (1=not clear at all, 5=very clear)

Overcoming Language Barriers In Global E-Learning Platforms

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ABSTRACT:

The global expansion of e-learning has introduced new opportunities for inclusive education but has also highlighted persistent challenges—particularly language barriers that hinder equitable participation among linguistically diverse learners. Many platforms rely on dominant languages, leaving non-native speakers at a disadvantage in terms of comprehension, engagement, and retention. This study explores how digital tools and pedagogical strategies can be leveraged to overcome language barriers in global e-learning environments. The research adopts a mixed-methods approach, combining literature analysis with case studies involving multilingual learners interacting with major e-learning platforms. Strategies examined include automated translation, multilingual subtitles, culturally responsive content, and interface localization. Key findings reveal that integrating language-accessible features improves comprehension, learner confidence, and course completion rates. However, challenges such as translation inaccuracies and lack of cultural nuance remain significant. Practical implications highlight the need for content creators and instructional designers to combine machine translation tools with human oversight, develop platform features in multiple languages, and embed inclusive language practices from the course design stage. Socially, language-inclusive e-learning fosters global collaboration, digital equity, and increased access for underserved populations.

KEYWORDS: Language Accessibility, Multilingual Learning, E-Learning Platforms, Digital Inclusion, Global Education, Cultural Responsiveness.

1.Introduction

Over the past decade, e-learning has transformed the way people access education, breaking down geographical barriers and offering flexible, self-paced learning opportunities. However, for many learners worldwide, merely having an internet connection is not sufficient. Language remains a significant hurdle. According to projections by UNESCO (2025), approximately 40% of the global population cannot study in a language they understand fluently. In some low- and middle-income countries, this figure rises to 90%, leaving over 250 million students struggling to learn online.

Most major platforms default to a handful of dominant languages, particularly English, placing non-native speakers at a considerable disadvantage. When learners cannot fully grasp the language of instruction, they experience lower comprehension, diminished confidence, and higher dropout rates. This phenomenon undermines digital inclusion and exacerbates educational inequality, especially in multilingual and multicultural settings.

This study investigates how technology and pedagogical strategies can bridge the language gap. It examines approaches such as automated translation, multilingual captions, culturally responsive course materials, and localized interfaces. The objective is to identify methods that enhance understanding, boost learner confidence, and increase course completion rates while acknowledging the limitations of existing tools, such as mistranslations and lack of cultural sensitivity.

By integrating a review of current research with real-world case studies, this study captures both the rationale behind learners' experiences and the data that reflect what is effective. Practical challenges, such as limited internet access, are also addressed, highlighting areas where technological interventions still fall short.

The central conclusion is that language-inclusive features significantly enhance learner outcomes. Nonetheless, machine translation remains imperfect, and cultural nuances are frequently lost. The study advocates for a hybrid model that combines AI tools with human oversight and emphasizes the need to embed inclusivity from the outset of course design.

2.Literature Review

2.1Language Barriers in E-learning

Language-related challenges in online education are longstanding but have become more pronounced as digital learning expands globally. When platforms rely on one or two dominant languages, non-native speakers often face significant barriers. They struggle with comprehension, avoid participation, and are more likely to discontinue courses. UNESCO (2025) underscores the urgency of addressing these disparities in global education systems. Tchao and Agyekum (2011)

note that language mismatch leads to lower motivation and higher attrition rates among learners.

2.2 Multilingual Education and Digital Inclusion

Recent studies emphasize the benefits of integrating learners' first languages into educational content. Multilingual education enhances literacy, cognitive development, and socio-emotional engagement (Agyekum et al., 2012). Learners given the option to toggle languages or access subtitles demonstrate improved engagement and comprehension (Lee et al., 2022). Culturally responsive materials, aligned with learners' real-world contexts, further deepen understanding and promote collaborative learning (Mensah & Zhou, 2023).

2.3 Technological Solutions

Technological innovations such as AI-based translation, multilingual captions, and localized interfaces offer practical means of extending reach to linguistically diverse learners (Tchao and Agyekum, 2011; Agyekum et al., 2012). However, these tools are limited. Machine translations often generate awkward or inaccurate phrasing and fail to convey cultural nuances. AI translation tools must be complemented with human editing by bilingual educators or subject matter experts to ensure both accuracy and relevance (Rahman et al., 2023). Inclusive platforms should incorporate language support at the core design level, rather than as post-development add-ons (Okafor & Delgado, 2021).

2.4 Gaps and Opportunities

Despite technological advancements, there is a lack of holistic research examining the combined effect of technology and pedagogy in multilingual e-learning. Agyekum et al. (2012) call for studies that integrate learner perceptions and performance outcomes to identify adaptable and scalable solutions. Further research is needed to assess the sustainability and long-term impact of culturally inclusive digital education.

3. Research Methodology

This research employed a mixed-methods approach to examine the effectiveness of language-accessible features in e-learning platforms.

3.1 Qualitative Strand

An exploratory case study design was used. Semi-structured interviews and focus group discussions were conducted with 28 multilingual learners enrolled in online courses across Coursera, Moodle, and edX platforms. Participants were selected using purposive sampling based on language diversity and prior e-learning experience.

rience. A multilingual learner was defined as any student who speaks two or more languages and has taken an online course delivered in a language other than their mother tongue.

Interview guides were developed and pilot-tested for clarity. Thematic analysis was conducted using an inductive approach, identifying recurring themes such as usability, cultural relevance, and translation quality. Trustworthiness was enhanced through peer debriefing and triangulation of responses.

3.2 Quantitative Strand

Quantitative data were collected via surveys and platform analytics from a sample of 120 users. The surveys measured changes in comprehension, engagement, and completion rates before and after introducing language-accessibility tools, including automated translation, bilingual subtitles, and localized dashboards.

Instrument reliability was ensured through Cronbach's alpha (average $\alpha = 0.82$), and data validity was verified through expert review. Ethical approval was obtained from the university's research ethics board. Informed consent was secured, and participants' identities were anonymized.

4. Findings and Discussion

4.1 Stronger Comprehension and Engagement

Participants consistently reported improved comprehension and comfort navigating content when multilingual features were introduced. Quantitative data revealed increased engagement and completion rates.

4.2 Machine Translation Pitfalls

Automated translations were found helpful but inconsistent, particularly in technical or domain-specific content. Several learners highlighted confusion stemming from mistranslated terms.

4.3 Value of Cultural Relevance

Courses that included culturally familiar examples, idioms, and visuals were rated higher in learner satisfaction. For example, one participant noted, "When the economics course used local market scenarios instead of Western ones, I felt like the content spoke to me."

4.4 Need for Human Oversight

Platforms that incorporated human-edited translations achieved higher learner satisfaction, combining AI efficiency with linguistic and cultural accuracy.

4.5 Context Matters

In areas with limited connectivity, real-time translation tools were less accessible. Asynchronous features such as downloadable subtitles were more effective in such contexts.

These findings reinforce the literature that blended solutions—AI plus human input—offer the most comprehensive support (Rahman et al., 2023; Mensah & Zhou, 2023).

Table 1: Learner Engagement by Language Accessibility

Feature	Engagement Rate (%)	Completion Rate (%)
No Language Support	45	38
Automated Translation Only	60	50
Translation + Human Review	75	68

**Source: Aggregated platform analytics, June 2025*

Recommendations

- Integrate AI translation with expert bilingual review.
- Develop multilingual content and interfaces from inception.
- Design culturally responsive content aligned with learner contexts.
- Enhance infrastructure for offline access in low-connectivity regions.

5. Conclusion and Future Directions

This study demonstrates that language-accessible e-learning features such as translation, subtitles, and culturally aligned materials significantly improve comprehension and retention for multilingual learners. Nevertheless, translation quality and cultural nuance remain challenges.

Future research should explore scalable human-in-the-loop translation models, interoperability of language tools across platforms, and alignment with global accessibility standards (e.g., WCAG). Moreover, long-term studies are required to evaluate the effectiveness of culturally responsive pedagogy in varied linguistic settings.

6. Acknowledgements

This work was carried out as part of a broader digital inclusion initiative at Bindura University of Science Education, Zimbabwe. The authors extend gratitude to the participating learners, platform administrators, and colleagues whose insights were invaluable to this research.

7. References

- Agyekum, K., Owusu-Ansah, A. and Mensah, A. (2012) 'The impact of multilingual subtitles on learner engagement in e-learning platforms', *International Journal of Educational Technology*, 8(3), pp. 45–60.
- Lee, S., Yang, M. and Chen, J. (2022) 'AI-assisted translation tools in higher education: Learner perspectives and outcomes', *Journal of Educational Technology Research*, 14(2), pp. 102–119.
- Mensah, A. and Zhou, L. (2023) 'Culturally inclusive e-learning design: Strategies and learner feedback', *International Review of Digital Learning*, 11(1), pp. 33–50.
- Okafor, N. and Delgado, R. (2021) 'Designing inclusive digital platforms: Language access in the Global South', *Journal of Inclusive Technology*, 6(1), pp. 20–36.
- Rahman, A., Singh, P. and Boateng, E. (2023) 'Human-in-the-loop AI translation: A review of models and use in education', *Educational AI Review*, 5(3), pp. 55–75.
- Tchao, E. and Agyekum, K. (2011) 'Machine translation in online learning: Opportunities and challenges', *Journal of Digital Education*, 5(2), pp. 22–35.
- UNESCO (2025) *Global Education Monitoring Report: Language Inclusion in Digital Learning*. Paris: UNESCO.

Early Access, Lasting Impact: The Case For E-Learning In Early Education

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ABSTRACT:

This study investigates the impact of early access to digital tools on the development of digital skills and learning behaviors among children in Ghanaian public basic schools. While national policies promote ICT in education, implementation gaps persist, often excluding children from meaningful digital engagement during their foundational years. Using a mixed-methods approach, the study explored current digital learning experiences, identified challenges and opportunities, assessed the role of community and parental support, and suggested strategies for promoting early digital engagement in low-resource contexts. Findings indicate that early exposure to digital tools positively influences learning outcomes, particularly by enhancing information access, research autonomy, and adaptability to digital environments. However, disparities in device ownership, inconsistent access to ICT facilities, limited digital safety instruction, and emotional responses to reprimand remain significant barriers. The study highlights the importance of early, guided, and emotionally supportive ICT engagement in basic education. Due to time and verification constraints, the study did not include interviews with teachers, parents, or children suggesting an essential direction for future research. The findings contribute to ongoing efforts to promote equitable and meaningful digital inclusion in Ghanaian education.

KEYWORDS: E-learning, ICT, Curriculum, Access, Children, Parents

1.0 Introduction

This paper explores the impact of early digital exposure on the development of digital habits and skills among children in Ghanaian public basic schools. While e-learning platforms like Zoom and virtual classrooms have become essential in modern education, much of Ghana's digital focus remains on tertiary students and young professionals, with limited attention to children—the future beneficiaries of these technologies.

Parental concerns about online safety, addiction, and health risks, along with financial limitations, low digital literacy, and poor school infrastructure, often delay children's access to technology. As a result, many pupils enter tertiary institutions with minimal ICT experience, having only recently acquired basic digital skills.

The study focuses on children in public basic schools, guided by the definition of childhood in Ghana's Children's Act (1998, Act 560) and the UN Convention on the Rights of the Child. Despite policy frameworks such as the Ghana ICT for Accelerated Development (ICT4AD) Policy (2003) and the ICT in Education Policy (2015), early learners in public schools are frequently excluded from meaningful digital engagement, reinforcing existing digital divides.

1.1 Rationale and Research Agenda

While digital integration is progressing in secondary and tertiary institutions, many public basic schools lack functioning ICT labs, trained staff, and consistent resources. Low parental digital literacy further limits home-based support for children's learning. This study investigates how early digital exposure shapes children's learning experiences, with a focus on urban and peri-urban public schools.

The research aims to explore current digital learning experiences, identify challenges and opportunities, assess the role of community and parental support, and recommend strategies for promoting early digital engagement in low-resource contexts.

Using a qualitative design, the study employed open-ended survey questions to gather participants' reflections. Responses were thematically analysed to uncover key patterns related to early access and ICT use.

2.0 Literature Review

2.1 Introduction to Digital Literacy

Digital literacy has become a critical skill in today's technology-driven world. Globally, the rapid growth of digital technology has created new opportunities but also exposed gaps, particularly in access and skills. In Ghana, these challenges are es-

pecially evident among children in rural and low-income areas, where many lack access to digital devices and quality digital education (Assan, 2025).

A recent Ghana Statistical Services report revealed that 2.6 million school children did not use any ICT device in the three months leading up to the last Census Night (Ghana Statistical Services, 2023), highlighting a significant digital divide. This gap threatens to leave behind a generation that will struggle to compete in the 21st-century workforce. The United Nations estimates that by 2050, Africans will make up 25% of the world's population (United Nations, 2024), while young Africans are expected to make up 42% of global youth (African Union Commission, 2019). This demographic trend demands urgent attention to equip young people with digital skills that align with future labor market needs.

Several studies support the importance of addressing these gaps early. Yakubu and Boateng (2023) explored perceptions and practices of ICT integration among teacher trainees in Ghanaian Colleges of Education. Their findings indicated that practical digital engagement during training enhanced both confidence and readiness to teach ICT. Likewise, a national ICT access study (Anane, 2019) reported that only 4% of primary schools and 10% of JHS had computers, pointing to persistent infrastructure gaps that hinder equitable digital learning. In a related study, Acquaye and Appiah-Dankwah (2023) examined the digital literacy levels of basic school teachers in Ghana and found that despite positive attitudes toward technology, actual classroom application was limited by both skill and policy clarity.

2.2 Efforts to Bridge the Digital Divide

Several organizations, such as Literacy Africa, are working to bridge this divide by introducing mentorship and digital literacy projects that target rural students. These initiatives aim to empower youth with STEM education and other 21st-century skills necessary for socio-economic development.

Children's interaction with digital technology goes beyond mere access. Research by Acquaye and Agbeviv (2025) shows that Ghanaian children fantasize about digital devices as part of an ideal childhood. They see technology as a source of education, leisure, and adventure, focusing mainly on its positive effects. This finding suggests that integrating digital tools into school curricula could enhance learning experiences and align with children's aspirations.

2.3 Barriers to Access

Access to technology is influenced by multiple barriers such as financial constraints, limited network coverage, infrastructure gaps, and cultural attitudes, especially in rural areas. Gender disparities also exist, with girls often facing greater challenges in accessing digital education (UNICEF, 2017). Moreover, existing edu-

cational frameworks need to integrate ICT more effectively by training teachers and making digital literacy a core part of subjects like math and English.

2.4 Health and Safety Concerns

As digital technologies become increasingly embedded in children's lives, concerns regarding their potential impact on health and well-being have grown. Prolonged screen time has been associated with a range of physical health issues, including eye strain, disrupted sleep patterns, and musculoskeletal problems caused by poor posture (Hill et al., 2016). Psychologically, excessive or unregulated screen use has been linked to reduced attention spans, increased sedentary behavior, and digital dependency or technology addiction, particularly when screen time replaces physical activity or social interaction (Twenge & Campbell, 2018).

Nonetheless, research suggests that early exposure to technology, when accompanied by age-appropriate guidance and balanced routines, can support positive learning and development outcomes (Radesky et al., 2020). The use of digital health tools, screen time management applications, and parental control features can help families set boundaries and encourage mindful engagement with technology. Schools and caregivers have a crucial role to play in modelling healthy digital habits, monitoring content, and ensuring that ICT use complements, rather than replaces, holistic child development.

2.5 Online Safety Challenges

Safety online remains a critical issue. Despite a young population where children under 18 make up over 40% of Ghana's population (Ghana Statistical Service, 2021), legislation protecting children in the virtual space is underdeveloped. Many children access the internet primarily through mobile devices at home, exposing them to online risks including scams, cyberbullying, and inappropriate content. While some government programs promote ICT education, supervision and parental awareness remain essential to protect children in cyberspace (Law and Development Associate Group, 2018).

3.0 Research Methodology

This study employed a mixed-methods research design to examine how early access to digital tools influences the development of digital skills and habits among children in public basic schools in Ghana. The mixed-methods approach was selected to enable both quantitative analysis of response patterns and qualitative exploration of personal experiences and perceptions.

Data were collected through an online survey administered via Google Forms. The survey targeted 24 young adults who had completed their basic education in Ghana, enabling retrospective insight into their digital learning experiences. Respondents were recruited using purposive sampling through educational platforms and social networks focused on Ghanaian tertiary students, with the goal of obtaining participants who had experienced public basic education within the last 10 years. This sample size, while modest, provided a sufficient range of responses for thematic analysis and preliminary trend observation, especially given the exploratory nature of the study.

The survey instrument consisted of both closed-ended questions, which generated numerical data on access to devices, ICT lab availability, and usage patterns, and open-ended questions designed to elicit in-depth reflections from participants. No personal identifiers were collected, in adherence to ethical standards of privacy and confidentiality.

Quantitative data were analyzed using simple descriptive statistics to identify trends and disparities in access and usage. Qualitative responses were subjected to thematic analysis, allowing the researchers to identify recurring patterns, notable contradictions, and contextual nuances related to technology access and learning.

This mixed-methods framework provided a richer, more holistic understanding of the digital learning environment in public basic schools and the long-term implications of early ICT access.

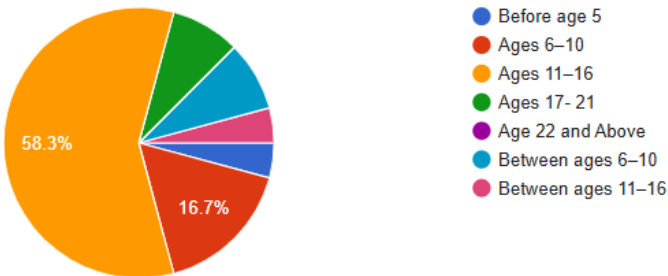
4.0 Findings and Discussion

The findings from the survey responses highlight significant insights into the use of e-learning devices, Information and Communication Technology (ICT) education, and access to technological tools among respondents during their basic education. This discussion synthesizes the survey data with existing literature to explore key patterns and contextual influences.

4.1 Early Exposure to E-Learning Devices

When did you first use E-learning devices such as computers or mobile phones?

24 responses



The data reveals varied timelines for the first use of e-learning devices among respondents. While a few engaged with digital tools before age five, others gained access only in their teenage years. Respondents from private schools typically experienced earlier exposure, supported by both institutional infrastructure and parental provision at home.

However, early access alone did not guarantee effective engagement. A recurring issue in the responses was that digital access in public schools often lacked continuity or practical depth. In addition to infrastructure limitations, participants described punitive reactions to unauthorized ICT use and minimal instruction on safe usage. These narratives suggest that early access without structured guidance or emotional support may not yield lasting digital fluency. Furthermore, the absence of discussions on barriers such as insufficient teacher training, unreliable electricity, and socio-cultural norms that limit children's digital autonomy showcases a key oversight in implementation.

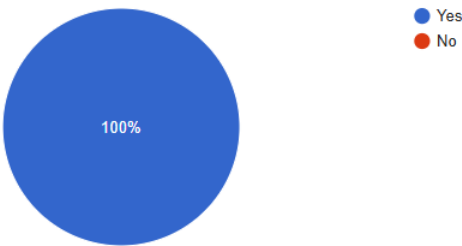
The study therefore extends previous literature by emphasizing not just the importance of access, but the compounded effect of access quality, instructional design, and contextual support in ensuring digital readiness. Addressing these elements is crucial to ensure that early access truly results in lasting impact. Tools into the learning process at an earlier stage, often supported by fee-paying parents who can provide supplementary access at home.

The timing of first exposure to digital technology is critical, as research shows that early engagement with e-learning tools contributes to greater digital fluency, confidence, and self-efficacy in later academic and professional settings (Livingstone and Helsper, 2007; Warschauer, 2004). Therefore, the delayed access reported by many public-school participants in this study may not only reflect infrastructural inequities but may also have implications for their long-term digital competence and adaptability in increasingly digitized learning environments.

4.2 ICT Education in Basic Schools

Were you taught Information Communication and Technology (ICT) in basic school?

24 responses



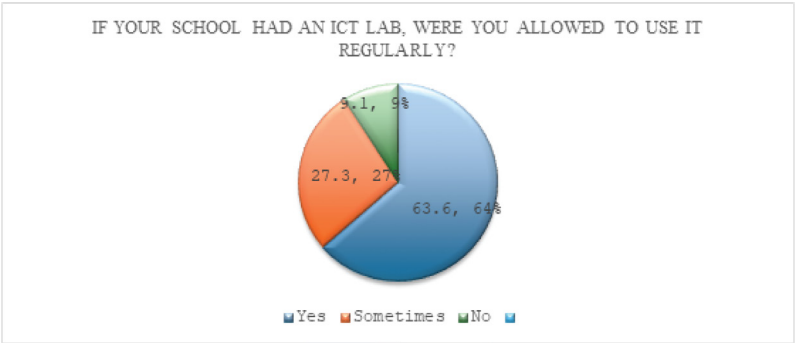
All respondents (100%) indicated that ICT was part of their basic school curriculum, suggesting near-universal inclusion of technology education at the policy level. However, their narratives revealed significant variation in the quality, delivery, and practical depth of ICT instruction. Private school respondents frequently described their ICT lessons as “exciting,” “insightful,” and “interactive,” reflecting experiences that included hands-on use of computers, project-based learning, and access to up-to-date software and internet resources. In contrast, public school attendees tended to describe their ICT education as “helpful” but limited by infrastructural and logistical constraints—including irregular access to functional computers, outdated teaching materials, and infrequent use of laboratories.

This disparity is consistent with prior research highlighting the uneven implementation of ICT curricula in developing country contexts. Olatokun and Folaranmi (2008) emphasize that while national education policies often mandate ICT instruction, actual delivery is constrained by disparities in school funding, staff training, electricity supply, and equipment availability—factors which disproportionately affect public and rural schools. Similarly, Adekunle and Adegoke (2019)

found that the presence of ICT in the curriculum does not always translate into effective teaching and learning; instead, the efficacy of ICT education depends on the quality of teacher preparation, infrastructure maintenance, and institutional prioritization of digital literacy.

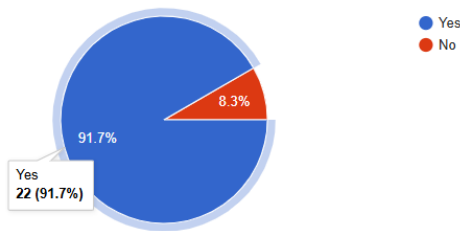
Moreover, scholars such as Buabeng-Andoh (2012) argue that for ICT education to be meaningful, it must go beyond theoretical exposure to include consistent, hands-on practice—especially at the basic education level where foundational digital skills are first formed. The contrasting accounts from respondents in this study reinforce the notion that policy-level inclusion of ICT is insufficient on its own; successful implementation must be supported by targeted investments in infrastructure, teacher development, and pedagogical reform to ensure equitable learning experiences.

4.3 Access to ICT Facilities and Resources



Did your school have an ICT laboratory?

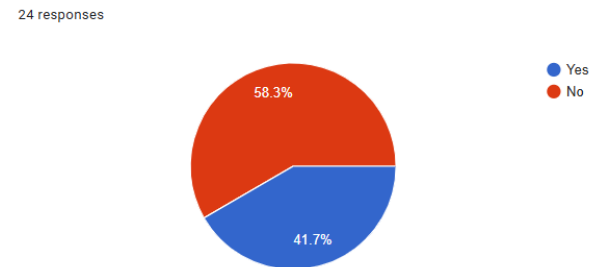
24 responses



Nearly all respondents indicated that their schools had ICT laboratories, with only two reporting the absence of such facilities. However, access to these labs varied notably. Of the 22 respondents whose schools had ICT laboratories, 2 (9%) reported no access, 6 (27%) had irregular access, and only 14 (64%) enjoyed regular access. This variation suggests that the mere presence of ICT infrastructure does not guarantee its effective use. Factors such as administrative restrictions, scheduling constraints, or insufficient equipment may account for limited access in some schools. These findings are consistent with broader literature highlighting that inconsistencies in ICT access across schools often stem from infrastructural limitations, resource constraints, and lack of integration into daily teaching practices (Sey, 2013; Ofosu-Asare, 2024). Such uneven exposure to technology at the basic education level can contribute to disparities in digital literacy and e-learning readiness among learners.

4.4 Personal Ownership of Devices

Did you personally have access to a computer or mobile phone while in basic school?



Ownership of personal devices during basic education emerged as another area of disparity. Out of 24 respondents, 58.3% (14 individuals) reported not having a personal laptop or mobile phone during their basic school years, underscoring a significant gap in early access to digital technology. Participants also described being reprimanded for using technological devices in school under various circumstances. One respondent shared: “My classmates and I went to the [ICT] lab when it wasn’t ICT period on the timetable,” while another noted that such scolding occurred because “[the phone] became a distraction.” Several respondents reflected on the emotional toll of these experiences, with one stating, “yes, many times. It was a sad feeling.” Although this study did not investigate the long-term effects of such emotions, existing literature suggests that negative but non-traumatic emo-

tional experiences in educational settings can shape learners' future attitudes and behaviours. Repeated experiences of sadness or reprimand related to ICT use may, over time, foster aversion, reduce digital self-efficacy, or lead to disengagement from technology (Pekrun, 2006; Baumeister et al., 2001; Hargittai & Dobransky, 2017). Such findings underscore the importance of fostering emotionally supportive ICT learning environments during early childhood.

4.5 Online Security

Although the majority of respondents (70.8%) indicated that they did not encounter online threats during their early use of ICT, a notable minority (29.2%) reported experiences such as scams, inappropriate content, or instances of cyberbullying. While these cases were not widespread, their presence highlights the potential risks associated with unsupervised or unmediated digital engagement among children. These threats may be more pronounced for users who accessed the internet outside structured school environments, particularly when digital literacy or parental guidance was limited.

The findings show that it is important to view digital literacy not only as a set of technical skills, but also as a critical component of online safety education. Scholars such as Livingstone and Haddon (2009) have argued that children's online experiences are shaped not only by access but also by their ability to navigate digital risks. In low-resource educational settings, however, the emphasis on cybersecurity or ethical digital use is often minimal (Buabeng-Andoh, 2012).

As Ghana scales up its efforts towards digital inclusion, it is essential to incorporate digital safety curricula that include topics such as phishing awareness, cyberbullying, and privacy protection. This will equip young learners to use technology safely and responsibly.

4.6 Perceived Impact of Early ICT Access on Learning

Respondents were asked whether early access to technology had influenced their learning. The majority reported positive educational impacts, citing benefits such as faster access to information, increased learning flexibility, and alignment with the digital demands of contemporary education. One respondent noted, *"it aligned me to the evolving world of technology"*, while another emphasised that *"access to information was quicker, allowing me to learn faster."* For learners from resource-constrained backgrounds, technology often served as a substitute for

scarce learning materials: *“When I couldn’t afford textbooks, having a phone and laptop made learning easy because I could just search and find all answers on a PC with just a little data.”*

These responses echo findings from Warschauer (2004), who argues that early digital engagement enhances not only access to information but also learner autonomy, particularly among students from underserved environments. Similarly, Hohlfeld et al. (2008) found that students with consistent access to ICT tools tend to exhibit improved research skills, greater confidence in digital environments, and better adaptation to tertiary-level digital learning platforms.

However, a minority of respondents reported less positive or neutral experiences. One respondent recounted that “from basic school to university, I didn’t have knowledge of it so I really struggled with my CSM [Computer Science Module] on campus,” suggesting that delayed exposure to ICT can hinder learners’ capacity to cope with technology-dependent academic tasks at higher levels of education. Another remarked that “with or without technology, I always had access to books,” implying that access to ICT may not have been a decisive factor in his learning trajectory. These perspectives align with research by van Dijk (2006), who distinguishes between material access to ICT and the effective use of such tools for educational purposes—a distinction that helps explain variation in perceived impact.

Taken together, the responses support the view that early access to technology can be a significant educational enabler, especially when it complements rather than substitutes traditional learning resources. Yet they also illustrate that the benefits of ICT use are not uniform, and depend on broader contextual factors such as digital literacy, institutional support, and the learner’s own adaptability.

5.0 Summary and Discussion of Findings

This study shows that early access to ICT and e-learning tools varies significantly, shaped by differences in school infrastructure, family resources, and the quality of implementation across institutions. Although ICT appears in the basic school curriculum across all respondents, the learning experiences it enables are far from consistent. Respondents from private schools generally described more hands-on, engaging ICT education, while those from public schools often encountered limited access, outdated resources, and less frequent use—conditions that mirror patterns discussed in existing literature on digital inequality.

The accounts gathered suggest that early access to digital tools can enhance learners' autonomy, accelerate information access, and ease transitions to digital learning environments, particularly when other learning resources are scarce. At the same time, a few respondents described delayed exposure and limited ICT competence, which affected their academic performance later in life. These mixed experiences suggest that the benefits of ICT depend not only on access, but also on the quality of support, emotional context, and sustained engagement. Addressing these issues requires more than infrastructure; it calls for careful integration of digital tools into pedagogy and broader efforts to ensure that all learners are equipped to participate meaningfully in digital education.

6.0 Practical Implications and Strategic Recommendations

Although the paper offers insights into digital inclusion efforts in Ghanaian education, the findings also call for actionable strategies to promote early digital engagement, especially in low-resource contexts:

1. **Community ICT hubs:** Establish ICT centers in underserved areas that provide scheduled access and basic digital training for children.
2. **Parent digital literacy campaigns:** Introduce workshops or media campaigns that provide parents with basic ICT knowledge, enabling them to guide their children more effectively.
3. **Digital mentorship in schools:** Implement peer mentorship programs where older students with ICT proficiency supports younger learners.
4. **Low-cost device schemes:** Partner with NGOs or tech companies to distribute affordable devices to families and schools in resource-poor areas.
5. **Teacher training modules on Early ICT instruction:** Update teacher training curricula to include pedagogical methods for guiding young children through digital learning experiences safely and effectively.

Incorporating these strategies would not only support the early development of digital skills but also help reduce the digital inequalities identified in the study.

7. Conclusion and Further Research

This study examined how early access to digital tools influences learning among children in public basic schools and their future academic endeavours. Using a mixed-methods approach, it found that early digital exposure often supports learning by improving access to information, developing research habits, and fostering adaptability in digital environments. However, inconsistencies in access, quality of ICT instruction, and digital safety education remain significant challenges.

Due to time constraints and difficulties in verifying identities, the study did not include interviews with teachers, children, or parents. Data collection relied entirely on open-ended survey responses. While this offered valuable insights, future research would benefit from including in-depth interviews to provide a more comprehensive view.

Though this study did not focus on socio-economic backgrounds and gender gaps, these remain important areas for further investigation. Future studies might also examine how early ICT exposure affects long-term academic or career outcomes, or how cultural and parental attitudes shape digital habits in children.

Overall, the findings highlight the need for early, guided, and emotionally supportive integration of ICT into basic education, beyond curriculum inclusion, to ensure meaningful and sustainable digital learning for all learners.

8. Acknowledgment

We thank God for the wisdom and strength throughout this research. Our sincere gratitude goes to our mentors, Dylan Harold, Daniel, and Edem Boso for their guidance, support and helpful feedback.

9. Reference

- Acquaye, V. N. A. and Agbevi, S. L. G. (2025). The Place of Digital Technology in Ghanaian Children's Fantasy of Ideal Childhood. *East African Journal of Education and Social Sciences* 6(2), 15-26. DOI: <https://doi.org/10.46606/eajess-2025v06i02.0432>.
- African Union Commission (2019). AFRICA'S FUTURE Youth and the Data Defining Their Lives POLICY BRIEF. African Union Commission.
- Baumeister, R.F., Bratslavsky, E., Finkenauer, C. and Vohs, K.D., 2001. Bad is stronger than good. *Review of General Psychology*, 5(4), pp.323-370. Available at: <https://doi.org/10.1037/1089-2680.5.4.323>
- Biney, G.A. and Adade, R. (2024). Digital Device Ownership, Digital Literacy and Information Technology Learning Self-Efficacy of Junior High School Students. *International Journal of Contemporary Sciences*, 1(7), pp.275-304. doi:<https://doi.org/10.55927/ijcs.v1i7.8975>.
- Buabeng-Andoh, C., 2012. Factors influencing teachers' adoption and integration of information and communication technology into teaching: A review of the literature. *International Journal of Education and Development using ICT*, 8(1), pp.136-155.
- Adekunle, A. and Adegoke, B., 2019. Challenges of implementing ICT curriculum in public secondary schools in Nigeria. *Journal of Education and Learning*, 8(3), pp.183-192.
- Ghana Statistical Service (2021). 2021 Population and Housing Census. Ghana Statistical Service.
- Ghana Statistical Service (2023). Monthly Press Release, June 2023. [online] statsghana, Ghana Statistical Service, p.1. Available at: <https://statsghana.gov.gh/gssmain/fileUpload/pressrelease/International%20Day%20of%20the%20African%20Child%20press%20release%20from%20GSS.pdf> [Accessed 8 Jun. 2025].
- Habti, H.E. (2022). Why Africa's Youth Hold the Key to Its Development Potential. [online] World Economic Forum. Available at: <https://www.weforum.org/stories/2022/09/why-africa-youth-key-development-potential/> [Accessed 8 Jun. 2025].

- Hargittai, E. and Dobransky, K., 2017. Old dogs, new clicks: Digital inequality in internet skills among older adults. *Canadian Journal of Communication*, 42(2).
- Hill, D., Ameenuddin, N., Reid Chassiakos, Y. (Linda), Cross, C., Hutchinson, J., Levine, A., Boyd, R., Mendelson, R., Moreno, M. and Sue Swanson, W. (2016). Media and young minds. *Pediatrics*, [online] 138(5). doi:<https://doi.org/10.1542/peds.2016-2591>.
- Hohlfeld, T.N., Ritzhaupt, A.D., Barron, A.E. and Kemker, K. (2008). Examining the Digital Divide in K-12 Public schools: Four-year Trends for Supporting ICT Literacy in Florida. *Computers & Education*, 51(4), pp.1648–1663. doi:<https://doi.org/10.1016/j.compedu.2008.04.002>.
- Law and Development Associate Group (2018). Children's Online Safety Concerns in Ghana: A Position Paper on Legislative and Policy Gaps. Accra: Department of Children, MoGCSP; UNICEF Ghana, p.5.
- Lim, W.M. (2024). What Is Qualitative research? an Overview and Guidelines. *Australasian Marketing Journal (AMJ)*, [online] 33(2), pp.199–229. doi:<https://doi.org/10.1177/14413582241264619>.
- Livingstone, S. and Helsper, E. (2007). Gradations in Digital inclusion: children, Young People and the Digital Divide. *New Media & Society*, [online] 9(4), pp.671–696. doi:<https://doi.org/10.1177/1461444807080335>.
- National Information Technology Agency (2003). Ghana ICT for Accelerated Development (ict4ad) Policy. National Information Technology Agency.
- Olatokun, W. and Folaranmi, M. (2008). Private and Public Schools Dichotomies in the Adoption and Use of Information and Communication Technology. *Information Technologist (The)*, [online] 5(1). doi:<https://doi.org/10.4314/ict.v5i1.32000>.
- Pekrun, R., 2006. The Control-Value Theory of Achievement Emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review*, 18(4), pp.315–341.
- Radesky, J.S., Schumacher, J. and Zuckerman, B. (2015). Mobile and Interactive Media Use by Young Children: The Good, the Bad, and the Unknown. *PEDIATRICS*, [online] 135(1), pp.1–3. doi:<https://doi.org/10.1542/peds.2014-2251>.
- Twenge, J.M. and Campbell, W.K. (2018). Associations between Screen Time and Lower Psychological well-being among Children and adolescents: Evidence from a population-based Study. *Preventive Medicine Reports*, 12(12), pp.271–283. doi:<https://doi.org/10.1016/j.pmedr.2018.10.003>.

UNICEF (2017). The State of the World's Children 2017: Children in a Digital World. New York: UNICEF Division of Communication.

United Nations (2024). Revised World Population Prospects 2024.

Van Dijk, J.A.G.M. (2006). Digital Divide research, Achievements and Shortcomings. *Poetics*, [online] 34(4-5), pp.221–235. doi:<https://doi.org/10.1016/j.poetic.2006.05.004>.

Venkatesh, V., Morris, M.G., Davis, G.B. and Davis, F.D., 2003. User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27(3), pp.425–478.

Warschauer, M., 2004. Technology and Social Inclusion: Rethinking the Digital Divide. Cambridge, MA: MIT Press.

Yakubu, M., & Boateng, J. (2023). ICT Integration in Teaching and Learning: Perceptions and Practices in Ghanaian Colleges of Education.

Anane, E. (2019). Basic School Computerization in Ghana: Infrastructure and Access. ERIC. <https://files.eric.ed.gov/fulltext/EJ1074173.pdf>

Acquaye, M. A., & Appiah-Dankwah, K. (2023). Digital Literacy Levels of Teachers in Public Basic Schools. University of Cape Coast Repository. <https://ir.ucc.edu.gh/xmlui/handle/123456789/10866>

Empowering Communities Through Digital Research Training And Continuous Professional Development (CPD): The Konandy Education And Research Foundation (KERF) Model.

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ABSTRACT:

E-learning has gradually become the norm of the day but teachers and students in some communities are being left behind due to digital illiteracy, lack of infrastructural facilities, and limited professional development opportunities for teachers. KERF Foundation, established by Ghanaian youth with support from educational experts/bodies have developed a community-based model to target students with Free Research Training (FRT) and Continuous Professional Development (CPD) for teachers. This paper highlights the design, implementation, and early outcomes of KERF Foundation's approach in its pilot of the model. The theoretical framework of the study is the Community of Inquiry (COI), and the researchers utilized the mixed method approach. Pre/Post training survey and observation was used in collecting data for CPD and FRT respectively, and a paired sample t-test was used to assess the effectiveness of the CPD pilot. With the pilot of the free research training yet to be implemented, several students have already expressed interest. Twelve volunteer teachers were recruited for the pilot of the CPD, and findings suggests low and no statistically significant difference for some pedagogical areas. Further research by the foundation should collect same dataset from a larger population to re-run t-test since this is a pilot study.

KEYWORDS: Research Training, Digital Learning, E-Learning, Community Based-Model, Continuous Professional Development (CPD)

1. Introduction

The world being a global village easily make an aspect of one's culture permeate into the culture of others. Raikhan et al., (2014) posit that there is a direct relationship between globalization and culture as globalization leads to changes in cultural patterns. Every sector of the Ghanaian economy including education is growing at a faster pace due to technological advancement and globalization, but this varies across industries and regions, especially remote communities. In the agricultural sector for instance, Addison et al., (2024) acknowledged Ghana to be a leading name in digital transformation in Africa but people in remote areas are being left behind. The educational sector is not an exception as the proliferation of e-learning, online learning, and the blended learning model have left people in remote communities behind due to poor internet connectivity, no or little electricity, and others (Olanrewaju et al., 2021).

Konandy Education and Research Foundation (KERF), a Ghanaian youth-led Non-Governmental Organization (NGO) with support from educational experts are making real-life contribution in remote communities. KERF is driven by its mission to "empower future generation of researchers." The foundation achieves this by providing free research training and educational resources to students. In Ghana, many tertiary students approach their final-year thesis as a mere formality for graduation, often overlooking the immense potential of research to drive societal change. To address this challenge, the founder of KERF, a passionate educational researcher, created the organization to instil an early appreciation for research among pre-tertiary students. By fostering this enthusiasm before they transition to tertiary education, KERF Foundation aims to nurture a generation of problem-solvers who view research as a tool for innovation and transformation.

Continuous Professional Development (CPD) for teachers is another area of interest for KERF as there is a direct relationship between improved learning outcomes and teaching strategies (Jalbani, 2014). KERF together with experts have developed a curriculum based on modern-day teaching strategies to help improve learning outcomes. The model was piloted in-person in a Ghanaian remote community with twelve volunteer teachers as beneficiaries. Majority of these teachers are not professionals in the Ghanaian regular school system, but they have sacrificed to volunteer as community teachers to help learners aged eleven years and below in their communities. This makes the KERF model a requisite for these teachers in building their capacity. The objectives of the study seeking redress include the effectiveness of the pilot of KERF's Continuous Professional Development (CPD), and the way forward of KERF's free research training program which is yet to be piloted.

2. Setting the Stage

There is a misconception that Africans do not value or appreciate research, but the actual problem is deeply rooted in limited funding and opportunities for young African researchers. “You have to work twice as hard if you are born in Africa.” This has been on the lips of many young Africans hoping to break barriers with their craft. There is a research gap in Africa which has caused many to be left behind (World Economic Forum, 2024), and Nabyonga-Orem et al., (2024) explored why many African researchers are left behind in global scientific publications.

There are signs of the Ghanaian government being actively involved in research, but no known research achievement can be attributed to the government as at now. The Ghana National Research Fund was established in 2020 under the Ghana National Research Fund Act (Act 1056) with a pledge of \$50 million as seed money (Bonney, 2025). It has been five years without the fund being operationalised, and just when research pundits began assuming it is nothing but a political gimmick, the current Minister of Education, Haruna Iddrisu in his six months of being in office has made a seed fund of GHC50 million available through the Ghana Education Trust Fund (GetFUND), and this is a step in the right direction (Twumasi, 2025). Other ways the Ghanaian government has shown involvement or interest in research is through initiatives and institutions such as the Ghana Innovation and Research Commercialisation Centre, the Ministry of Environment, Science, Technology and Innovation (MESTI), and the Council for Scientific and Industrial Research (CSIR).

In this context, management of KERF sees a reason to support the government and give back to Ghanaian communities through free research training programmes and teacher professional development. In its first year of operation, beneficiaries will be recruited to part-take in a free research training from experts to promote love for research and academia among the future generation. Future research training programs will be in collaboration with Ghanaian universities recruiting first year students as beneficiaries. The Continuous Professional Development (CPD) for teachers has already been piloted in a Ghanaian remote community ready to be implemented on a larger scale.

2.1 The KERF Model

The KERF model has been carefully designed to make beneficiaries professional researchers and educators after going through the training program. The maiden edition of the research training is fully online to create an opportunity for individuals in remote areas or marginalized communities to benefit from the training. Also, this medium is cost effective for people who will not be able to fund the cost

of transportation from rural locations to the central place of convergence for the training. KERF Model adopts the Community of Inquiry (COI) which was originally developed by Garrison, Anderson, and Archer (2000). Scholars have used the COI in various study seeking to improve learning outcome among students in an online, in-person, or hybrid medium. Wiredu et al., (2023) used the Community of Inquiry in assessing the Impact of the Blended Learning Model in improving learning outcomes among students.

The Community of Inquiry describes the necessary elements to create deep and meaningful learning. It as well outlines the educational experience happening at the convergence of three presences which are; cognitive presence, teaching presence, and social presence. The social presence is the ability of learners to be seen as real people as they are able to establish relationships, communicate online and offline, and project their emotions as well. The KERF model explores this through peer reviews and forum. Teaching presence is directly related to the facilitations making education meaningful and worthwhile. This ensures effective collaboration between teachers and students for effective facilitation. It is at this level of Community of Inquiry that the teaching is designed online and offline to engage students in collaborative constructivism. Cognitive presence is also related to the extent to which learners can construct and confirm meaning through sustained reflection and discourse.

The KERF Model for the research training begins with an advertisement for potential beneficiaries to express interest through social and traditional media. An independent panel consisting of experts in academia and the corporate environment review submitted applications to shortlist beneficiaries who are reached out with congratulatory messages via email. The annual research training is in 3-tiers with tier I dubbed "Research Appreciation Seminar." The main objective of the Research Appreciation Seminar is to spark curiosity, dispel fears around research, and show its value in solving real-world problems. Tier II begins the foundational research skills which seeks to inculcate essential research knowledge and skills to students. Students will be able to conduct research from scratch after benefiting from tier II. The final tier is themed "Advanced Research Practice" which deepen skills and provide hands-on experience with mentorship and presentation opportunities. The Continuous Professional Development for teachers has already been piloted with data collected from the field analysed in this study by means of appropriate statistical models.

2.2 Growth of the KERF Model

Konandy Education and Research Foundation (KERF) envisions the growth of its model using Coburn (2003) framework on rethinking scale. Coburn's framework looks at educational reform in a whole new perspective with emphasis on four components; Depth, Sustainability, Spread, and Ownership. Literature posits that educational reform is always subject to numbers but Coburn (2003) envisions a future where educational reforms will move beyond numbers to deep and lasting change. KERF thrives on quality over quantity which is seen in its screening of applicants. KERF's growth projection in line with Coburn (2003) framework on rethinking scale is elaborated below;

Depth: The KERF initiative is not a nine-day wonder. Hence, KERF seeks to put measures in place that will help the training program maintain a level of professionalism from the onset that will be maintained throughout the different phases of the initiative. Many projects begin poorly before implementers adopt change towards the welfare of the project, but this project differs as adequate provisions have been made for any change along the way so as not to alter or short live the aim and beliefs of KERF.

Sustainability: Just as the "going concern concept" in accounting postulates, the research training programme will be there for future foreseeable time. Every good project has a succession plan. This project is not tied to one institution or school. The KERF annual training has been phased into 3 tiers to enhance sustainability. Projections of the program's sustainability comes from the collaboration with pre-tertiary institutions and universities starting year two.

Spread: With an internal vision of being at the forefront of the Ghanaian educational system, the program will spread across all sixteen regions of Ghana starting from the capital. We envision spreading the program to other West African countries starting from Nigeria within our first five years of operation.

Ownership: A vision which was conceptualized and developed by a Ghanaian youth has now been accepted by other youth and educational experts. KERF envisions being accepted and owned by educational stakeholders including Senior High Schools, Universities, Communities, GETFUND, Ministry of Education (MoE) through the Ghana Education Service (GES) and others.

2.3 Community Based Intervention

Literature explores a number of community based intervention promoting experiential learning and social responsibility. Nchaga (2025) explored the opportunities and challenges associated with community based learning with particular emphasis on its impact on students, educators, and the community. Logistical and sustainability issues were some of the challenges encountered and the researcher suggested the inculcation of digital technologies to promote engagement. This literature is in agreement with the KERF model which has adopted the Coburn lens of scale to ensure sustainability together with the inculcation of digital technologies.

Community based learning is now part of many curricula worldwide (Shah et al., 2023), and a number of institutions and Non-Governmental Organizations (NGOs) are contributing their quota. In an experimental study conducted by Shah et al., (2023), improved learning outcome is a benefit associated with community based learning, and infrastructural needs are to be considered for implementation. The KERF model addresses the infrastructural gap through the integration of digital technologies such as online learning. Scanty materials exist on “research training” in peer-reviewed journals as it is normally conducted for learners in Higher Educational Institutions (HEI). This makes the KERF model a novel approach considering the targeted audience.

3.Methodology

The study reports on a free research training program for students, and a continuous professional development for teachers focused on enhancing teaching strategies to improve learning outcomes.

The mixed method research design was adopted for the study, and data was collected via Google forms. Twelve teachers from a remote Ghanaian community were recruited through voluntary participation for the pilot of the CPD model, and a quasi experimental pre-test/post-test design was employed to assess the effectiveness of the teacher professional development component. Observation from social media platforms, school networks, and youth groups shows a growing interest of students in the free research training which is yet to be piloted or implemented.

Paired sample t-test via Jamovi which is a data analysis software was used to assess the effectiveness of the CPD irrespective of the fact that some scholars disagree on the usage of t-test on a small sample size or datasets. An assumption

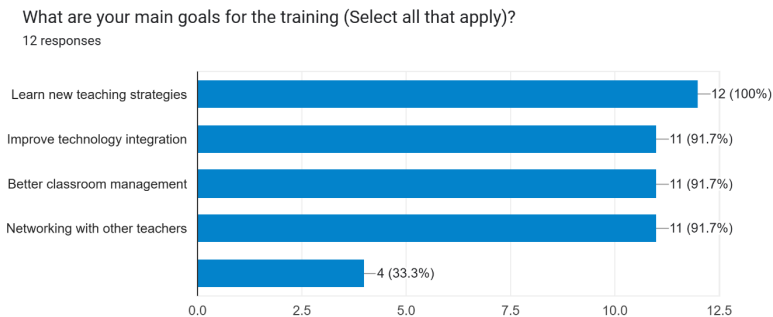
for the usage of t-test is the normality test, and the data passed the normality test using the Shapiro-Wilk test hence the adoption of t-test. Wilcoxon rank would have been appropriate for such a small dataset, but Wilcoxon rank is purposely for non-normality dataset which does not give enough credence for it to be used for this dataset which has already passed the normality test.

4.Data Analysis

4.1 Continuous Professional Development (CPD)

The beneficiary teachers included 75% females and 25% males with 50% falling within the age range of 20 to 30 years, and 50% within the age range of 31 to 40 years. 58.3% have a teaching experience of 3 to 5 years, 16.7% have an experience of 0 to 2 years, 16.7% have an experience of 11 years and above, and the remaining 8.3% have an experience of 6 to 10 years teaching children aged 11 years and below numeracy and literacy subjects. 25% of the teachers confirmed to have never participated in a professional development training with 75% answering affirmative. Challenges faced by these teachers in discharging their duties include lack of Teaching and Learning Materials (TLMs) and student engagement. Figure 1 below highlights the main reason of volunteer teachers joining the training program.

Figure 1. Main Reason for Joining the Training



Source: (Field Data, May 2025)

The main goals for joining the CPD training as elaborated in figure 1 was fully achieved at the end of the training program. The post training survey recorded 72.7% of teachers rating the overall quality of the training as good and the remaining 27.3% giving an excellent rating. 45.5% furthermore mentioned the training fully met their expectation and 54.5 mentioned it mostly met their expectation, and the entire participants (100%) mentioned recommending the training to other teachers.

The pre and post training survey collected data on the confidence level of volunteer teachers in the following areas before and after the training: Using technology in teaching; applying modern teaching strategies; classroom management skills; designing engaging lesson plans; and differentiated instruction for diverse learners. Table 2 below is an analysis of the data by means of a paired sample t-test using Jamovi. Pundits suggest a larger number of respondents is required for t-test (Frederick & Wallnau, 2016) as others are of the opposing view (Winter, 2013), but an assumption for conducting t-test is a normal distributed dataset, and the data has been proven by Shapiro-Wilk in table 1 to be normally distributed.

Table 1. Normality Test (Shapiro-Wilk)

		W	P
Using_Tech_Post	- Using_Tech_Pre	0.931	0.417
Modern_Strategies_Post	- Modern_Strategies_Pre	0.926	0.368
Classroom_Mgmt_Post	- Classroom_Mgmt_Pre	0.898	0.174
Engaging_Lessons_Post	- Engaging_Lessons_Pre	0.905	0.210
Differentiation_Post	- Differentiation_Pre	0.964	0.820

Note: A low p-value suggests a violation of the assumption of normality

Source: (Field Data, May 2025)

Table 2. Paired Samples T-Test

			Statis- tic	Df	P	Mean differ- ence	SE dif- ference
Using_Tech_Post	Using_Tech_Pre	Student's	2.206	10.0	0.052	1.091	0.495
Modern_Strategies_Post	Modern_Strate- gies_Pre	Student's	1.982	10.0	0.076	1.000	0.505
Classroom_Mgmt_Post	Classroom_ Mgmt_Pre	Student's	2.236	10.0	0.049	1.000	0.447
Engaging_Lessons_Post	Engaging_Les- sons_Pre	Student's	1.994	10.0	0.074	1.091	0.547
Differentiation_Post	Differentia- tion_Pre	Student's	0.714	10.0	0.492	0.364	0.509

Source: (Field Data, May 2025)

The paired sample t-test revealed statistically significant improvement in managing classrooms ($p = 0.049$) and marginally non-significant improvement in using technology (0.052) since it is a little above 0.05. Although other areas, such as applying modern strategies and designing engaging lessons, also showed positive shifts, they did not reach statistical significance. No substantial change was observed in differentiating instruction. These findings suggest that even in a small-scale pilot, targeted training can lead to measurable gains in specific pedagogical areas.

4.2 Free Research Training (FRT)

The Free Research Training program is yet to be implemented and the researchers observed a growing interest of students in the training program. KERF Foundation took to its social media pages to advertise this novel approach and it was warmly received by the public. An advertisement on LinkedIn for instance had a number of people exceeding the anticipated targeted beneficiaries expressing interest in the training program.

5.Findings and Discussions

The study highlights Konandy Education and Research Foundation models; Continuous Professional Development (CPD) and Free Research Training (FRT). Details are elaborated below.

5.1 CPD Findings and Discussions

Numerous studies suggest that small sample size relates to low statistical power, and Cao et al., (2024) affirms this in a clinical research where a comparison was made with a large and small sample size. A particular sample size denoted a statistically significant difference while another sample size showed no statistically significant difference in the same study. In the published book "Statistics for the Behavioral Sciences," Frederick & Wallnau (2016) recommends a minimum of thirty sample size to perform basic inferential statistics like t-test and confidence interval when the data is normally distributed and the variability is not too high. In our pilot study on professional development training program, paired sample t-test was still used though our sample size was lesser than the number suggested by Frederick & Wallnau (2016), but the sample size of twelve respondents achieved normality in Shappiro-Wilk normality test making t-test appropriate for the analysis. This is in consistent with a study conducted by Winter (2013) which shows no objection to using t-test on extremely small sample size. The study found out that there is a statistically significant difference in only classroom management with a p-value of 0.049. There is no statistical significant difference in using technology in teaching, applying modern teaching strategies, designing engaging lesson plans, and differentiating instruction for diverse learners. Though there is no statistical significant difference in the aforementioned variables, they all have a positive mean difference signifying a positive change comparing the pre-training results to the post training results.

A positive mean difference of 1.091 shows an improvement in the confidence of teachers in using technology in teaching and designing engaging lesson plans when pre and post training surveys are compared in both variables. Literature posits that technology in teaching improve learning outcomes and academic achievement (Monserate, 2018) so beneficiary teachers being confident to include technology into their teaching has the potential to improve learning outcome among their students. A positive mean difference of 1.000 shows there is an improvement in the confidence of beneficiary teachers in applying modern strategies to their teaching to help improve learning outcomes. Saro et al., (2022) found a statistical significant difference in applying modern teaching strategies which is not consistent with the findings of this study, but the findings of Saro et al., (2022) is not based on pre/post survey data, neither was it a pilot study or test. Beneficiaries pointed classroom management as part of their major challenges and this achieved statistical significant difference with a p-value of 0.049. The mean difference of 1.000 on the other hand shows a positive improvement in teachers confidence regarding classroom

management after the CPD. Though no substantial change was observed in differentiated instruction, the mean difference of 0.364 shows a small improvement in the confidence of beneficiary teachers to develop differentiated instruction for diverse learners.

5.2 FRT Findings and Discussions

Free research training program on the other hand adopting the KERF model is yet to be piloted with potential beneficiaries already expressing interest. Data will be collected to assess its effectiveness before implementing it on a larger scale. The researchers anticipate a successful training program with Key Performance Indicators (KPIs) under four thematic areas: Participation and Reach; Learning Outcomes; Engagement and Satisfaction; and Impact and Growth Potential.

KPIs under participation and reach will include the number of students enrolled in the training program, attendance rate, completion rate, and school representation. KPIs under learning outcomes will also include Pre/Post test score improvement, average score on final assessment, research confidence improvement, and the number of research proposals or projects completed. Under engagement and satisfaction, KPIs will include student satisfaction score which will be based on survey feedback after the training program. Additional KPIs will include feedback participation rate (students who completed post training surveys or evaluations), and student reflections or testimonials. KPIs under Impact and Growth on the other hand will also include students expressing interest in future training programs, number of students under mentorship after the training, public recommendation for future batches, and partnerships secured from individuals and corporate bodies.

6. Conclusion and Further Research

Starting with pre-tertiary or Senior High School students for the first year of the research training using e-learning, subsequent training seeks to target first year tertiary students across Ghana adopting the blended learning model (online and in-person). The blended learning model has been proven to improve learning outcomes among students (Utami 2018; Khader 2016; Wiredu et al., 2023) so it will be employed for the 3-tiers of the training programme.

Tier I which is a research appreciation seminar will be strictly in-person in a selected university through a collaborative effort with the Student Representative Council (SRC) and other appropriate bodies on campus. As a way of ensuring equality and equity among Ghanaian students, the KERF train will be moving annually to different tertiary institutions across the sixteen regions of Ghana. The module to be adopted for Tier II and III is yet to be concluded (TBC). As a non-profit making en-

tity with the sole motive of empowering the next generation of researchers and educators, KERF seeks to promote love for research and academia and improve learning outcome among students in the long-run. The foundation seeks to recruit 30 beneficiaries for the first cohort of the research training.

With Continuous Professional Development (CPD) for teachers already piloted, KERF seeks to take it to a higher level to reach out to numerous Ghanaian teachers to help improve learning outcome among students.

Further research or study will be conducted by the foundation delving deeper into the two areas of discussion: Free Research Training Program and Teacher Professional Development Program. The Continuous Professional Development (CPD) will be conducted for different group of volunteer teachers to have a large sample size, collecting the same pre and post training survey. This will create an opportunity to run another paired sample t-test with a larger dataset to assess the effectiveness of the training program under different conditions. Similar dataset will be collected during the pilot of the free research training program to assess its effectiveness as well.

7. References

Bonney, E. (2025, May 15). Graphic Online. Retrieved May 22, 2025, from [www.graphic.com.gh: https://www.graphic.com.gh/news/general-news/ghana-news-national-research-fund-to-be-operationalised-this-year.html#:~:text=The%20Ghana%20National%20Research%20Fund,fund%20had%20not%20been%20operationalised.](https://www.graphic.com.gh/news/general-news/ghana-news-national-research-fund-to-be-operationalised-this-year.html#:~:text=The%20Ghana%20National%20Research%20Fund,fund%20had%20not%20been%20operationalised.)

Coburn, C. E. (2003). Rethinking Scale: Moving Beyond Numbers To Deep and Lasting Change. *Educational Researcher*, 32(6), 3-12. <https://doi.org/10.3102/0013189X032006003>

Forum, W. E. (2024, February 11). World Economic Forum. Retrieved May 22, 2025, from [www.weforum.org: https://www.weforum.org/stories/2024/02/there-s-a-science-research-gap-in-africa/](https://www.weforum.org/stories/2024/02/there-s-a-science-research-gap-in-africa/)

Garrison, A. a. (2000). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education*, 2(2), 87-105.

Gideon Seun Olanrewaju, S. B. (2021). Left behind? The effects of digital gaps on e-learning in rural secondary schools and remote communities across Nigeria during the COVID19 pandemic. *International Journal of Educational Research Open*, 1-10. <https://doi.org/10.1016/j.ijedro.2021.100092>

Jalbani, L. N. (2014). Impact of Effective Teaching Strategies on Student's Academ-

ic Performance and Learning Outcome: A Literature Review. Institute of Business Management (Unpublished Thesis), 1-6. Retrieved from https://www.academia.edu/29881991/The_Impact_of_Effective_Teaching_Strategies_on_the_StudentsAcademic_Performance_and_Learning_Outcome_A_Literature_Review_Literature_Review_Education

Jeffrey M. Saro, M. E. (2022). New Normal Education: Strategies, Methods, and Trends of Teaching-Learning on Students' Perspectives and Its Effectiveness. *Psychology Education*, 5(1), 259-265. <https://doi.org/10.5281/zenodo>

Juliet Nabyonga-Orem, J. A. (2024). Why Are African Researchers Left Behind in Global Scientific Publications? – A Viewpoint. *International Journal of Health and Policy Management*, 1-4. <https://doi.org/10.34172/ijhpm.2024.8149>

Juliet Nabyonga-Orem, J. A. (2024). Why Are African Researchers Left Behind in Global Scientific Publications? – A Viewpoint. *International Journal of Health and Policy Management*, 1-4. <https://doi.org/10.34172/ijhpm.2024.8149>

Monica Addison, I. B.-A.-O. (2024). Exploring the impact of agricultural digitalization on smallholder farmers' livelihoods in Ghana. *Heliyon*, 10(6), 1-19. <https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e27541>

Monserate, C. A. (2018). Impact of Technology on the Academic Performance of Students and Teaching Effectiveness . *International Journal of Interdisciplinary Research and Innovations*, 6(1), 47-87.

Nchaga, A. M. (2025). Exploring Community-Based Learning: Opportunities and Challenges. *Research Output Journal of Arts and Management*, 4(1), 46-42. <https://doi.org/10.59298/ROJAM/2025/414652>

Rehan Shah, A. P. (2023). Making Community-Based Learning and Teaching Happen: Findings From an Institutional Study. *London Review of Education*, 21(1), 1-17. <https://doi.org/https://doi.org/10.14324/LRE.21.1.17>

Sadykova Raikhan, M. M. (2014). The interaction of globalization and culture in the modern world. *Procedia - Social and Behavioural Sciences*, 122, 8-12.

Seth Wiredu, E. A. (2023). Assessing the Impact of the Blended Learning Model on Student Learning Outcomes: A Case of KNUST MELS-IDL. *West African Journal of Open and Flexible Learning*, 12(1), 112-136.

Twumasi, K. O. (2025, June 4). Citi News. Retrieved June 7, 2025, from citinewsroom.com: <https://citinewsroom.com/2025/06/govt-allocates-ghs50m-to-national-research-fund-to-boost-innovation/>

Utami, I. S. (2018). The effect of blended learning model on senior high school students' achievement. SHS Web of Conferences, 42(2), 1-6.

Wallnau, F. J. (2016). Statistics for The Behavioral Sciences. (10th, Ed.) Cengage Learning.

Winter, J. d. (2013). Using the Student's t-test with extremely small sample sizes. Practical Assessment, Research, and Evaluation, 18(10), 1-11.

Ying Cao, R. C. (2024). Why is a Small Sample Size not Enough? The Oncologist, 29(9), 761-763. <https://doi.org/10.1093/oncolo/oyae162>

Designing The Ideal E-Coach: Personalizing Support For Digital Learners

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ABSTRACT:

As online learning continues to grow, learners often face challenges of disconnection both from the educational content and from their peers leading to diminished motivation and engagement. Personalized support has never been more critical in digital education, and the role of the E-Coach is emerging as a key solution to bridging this gap. This interactive workshop will guide participants through the development of an ideal E-Coach avatar, an essential support figure in online learning environments. Attendees will explore the defining characteristics, roles, and actions of an effective E-Coach, with an emphasis on how this role fosters academic success, emotional wellness, and learner persistence. Through hands-on activities and collaborative design, participants will identify the core attributes and competencies of a successful E-Coach, examine real-world strategies for delivering personalized support at scale, develop a practical framework for implementing E-Coaching systems within their own institutions, and gain access to tools and resources that can be immediately applied to enhance digital learner support. Designed for educators, instructional designers, and administrators, this session provides a roadmap to enhance online learner support systems. Participants will leave equipped with actionable insights to build or strengthen coaching infrastructures that address the diverse needs of digital learners boosting engagement, retention, and overall institutional outcomes.

KEYWORDS: E-Coach, Personalized Support, Engagement, Digital Learners, Retention

1. Introduction

The rise of digital learning environments has revolutionized access to education, offering unprecedented flexibility and reach. However, as institutions pivot to online and hybrid modalities, new challenges have emerged particularly regarding student engagement, motivation, and retention (Kahu, 2013). A recurring issue in online education is the sense of isolation learners often experience, which can negatively affect their academic persistence and emotional well-being (Bolliger & Inan, 2012). This growing disconnect calls for more adaptive and inclusive learner support mechanisms.

One increasingly prominent solution is the implementation of the “E-Coach”, a digitally embedded or human-supported role designed to provide personalized, scalable guidance to online learners. E-Coaches act as mentors, motivators, and support figures, helping students navigate not only the academic content but also the psychological and logistical demands of online education (Salmon, 2000). Despite the promise of E-Coaching, there remains limited consensus on its optimal design, delivery models, and institutional integration.

This paper aims to explore the attributes, competencies, and frameworks necessary to design an effective E-Coach system tailored for digital learning environments. The core objectives are:

- To identify key characteristics and roles of successful E-Coaches;
- To explore scalable strategies for implementing personalized E-Coaching;
- To propose a framework that educational institutions can adapt to meet diverse learner needs.

The research draws on a qualitative design-based approach, incorporating workshop-based insights, literature synthesis, and practical examples from existing E-Coaching models. While the study does not include primary empirical data collection, it leverages expert insights and participatory design methods to conceptualize a robust model for E-Coaching integration.

This investigation is intended to contribute to the evolving body of knowledge in digital learner support and inclusive e-learning strategies. It is particularly relevant for educators, instructional designers, and administrators seeking to enhance student engagement and institutional outcomes in online learning contexts.

2. Literature Review

The shift toward digital learning has accelerated the need for innovative support systems that address the unique challenges of online education. While flexibility and accessibility are often touted as benefits, digital learning environments can also lead to learner disengagement, reduced retention, and feelings of isolation (Bolliger & Inan, 2012). In response to these challenges, the concept of the E-Coach has emerged as a personalized, human-centered approach to guiding and supporting learners in virtual contexts.

2.1 Theoretical Underpinnings of E-coaching

E-Coaching is grounded in a combination of constructivist and socio-cultural learning theories, which emphasize the importance of interaction, scaffolding, and learner agency (Vygotsky, 1978; Bruner, 1996). Within these frameworks, the E-Coach serves not merely as a tutor but as a learning facilitator, motivator, and guide. Salmon (2000) introduced a five-stage model of e-moderation that positions digital facilitators as central to learner success starting from access and motivation, progressing through knowledge construction, and culminating in development and autonomy.

2.2 Key Roles and Competencies of E-Coaches

Effective E-Coaches possess a diverse skill set that combines pedagogical expertise, emotional intelligence, technological fluency, and mentoring ability (Caplan & Graham, 2004). According to Berge (1995), online facilitators play managerial, social, pedagogical, and technical roles, skills that directly overlap with those needed in E-Coaching. Moreover, the ability to recognize and respond to learners' emotional states is increasingly seen as critical. Research by Cleveland-Innes & Campbell (2012) underscores the importance of emotional presence in digital education, arguing that emotional scaffolding significantly enhances learner persistence.

2.3 Personalization and Adaptive Support

Personalized learning is a cornerstone of effective E-Coaching. This involves tailoring support based on individual learner data, preferences, performance trends, and motivational profiles (Pane et al., 2015). Adaptive coaching technologies and dashboards can aid human coaches in delivering timely and relevant interventions (Ifenthaler & Yau, 2020). Furthermore, the scalability of E-Coaching is being enhanced through AI-driven tools and learning analytics, which can help identify at-risk students early and recommend personalized outreach strategies (Johnson et al., 2016).

2.4 Institutional Integration and Challenges

Despite its promise, E-Coaching remains inconsistently adopted across institutions. Barriers include resource constraints, unclear role definitions, and lack of training (Vaill & Testori, 2012). However, institutions that have implemented E-Coaching programs such as the Open University in the UK report improvements in learner engagement and satisfaction (Rienties et al., 2018). There is growing recognition that systemic integration of E-Coaching into learning management systems (LMS) and student support structures is essential for achieving sustainable impact.

3. Research Methodology

This study adopts a qualitative, design-based research (DBR) approach to explore and articulate the core components of an effective E-Coach model within digital learning environments. Design-based research is particularly suitable for educational innovation studies where iterative development and practitioner collaboration are essential to producing actionable outcomes (Wang & Hannafin, 2005).

3.1 Research Design

The research was embedded within a structured workshop format, which serves as both a site of data collection and a collaborative design exercise. Participants include educators, instructional designers, and academic administrators with experience in digital learning contexts. The aim was to co-create a conceptual framework for E-Coaching grounded in both theoretical insights and practical experience. A single-cycle design iteration was implemented, consisting of the following phases:

- Contextual framing – Introducing participants to current E-Coaching practices and challenges.
- Collaborative ideation – Group discussions and brainstorming on essential E-Coach attributes and use cases.
- Framework synthesis – Consolidation of participant insights into a draft model for E-Coaching.
- Reflection and validation – Participant feedback on the emerging framework for accuracy and relevance.

3.2 Data Collection

Data will be collected through field notes, recorded discussions, participant-generated concept maps, and reflection sheets completed during the workshop. These diverse data sources will enable triangulation to enhance the credibility of the findings (Creswell, 2013). Consent would be obtained from all participants, and ethical considerations will be observed throughout the process.

4. Conclusion and Further Research

This paper will explore the design of an effective E-Coach model aimed at enhancing personalized support for digital learners. In response to increasing challenges of disengagement, isolation, and inconsistent learner outcomes in online education, the study will propose a structured framework grounded in both literature and participatory workshop input.

The findings should highlight the importance of relational, pedagogical, technological, and motivational competencies in E-Coaching roles. By consolidating these insights into an actionable framework, this research will offer institutions a practical guide for supporting digital learners at scale balancing automation with the human touch necessary to sustain engagement and success.

The implications of this study will be significant for educational institutions seeking to expand access and inclusion in digital learning contexts. The E-Coach model could enhance student satisfaction, retention, and achievement when integrated into institutional support systems, especially when aligned with learning analytics and early intervention tools.

However, the current research may have limitations, including its reliance on a single-cycle participatory workshop and a primarily conceptual scope. Future research should focus on conducting empirical validations of the proposed framework across diverse learner populations to ensure its generalizability and effectiveness. Additionally, studies should explore the comparative effectiveness of AI-assisted versus human-led coaching interventions to identify optimal support strategies. Investigating the longitudinal outcomes of E-Coaching programs on learner persistence and achievement will provide insights into their long-term impact. Finally, examining faculty training models is essential to sustainably scale E-Coaching capacity within institutions.

As online and hybrid education continue to evolve, embedding scalable, human-centered coaching mechanisms will be essential to delivering truly inclusive and adaptive e-learning experiences.

5. Acknowledgement

The authors extend their heartfelt appreciation to Prof. Eric Appau Asante and Mr. Christopher Addo for their mentorship, encouragement, and invaluable insights throughout the development of this work. The authors also acknowledge the support and collaboration of ACCESS Global and ACCESS Ghana, whose contributions greatly enriched the perspectives shared in this paper.

6. References

- Berge, Z.L., 1995. Facilitating computer conferencing: Recommendations from the field. *Educational Technology*, 35(1), pp.22–30.
- Bolliger, D.U. and Inan, F.A., 2012. Development and validation of the Online Student Connectedness Survey (OSCS). *The International Review of Research in Open and Distributed Learning*, 13(3), pp.41–65.
- Braun, V. and Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), pp.77–101.
- Bruner, J., 1996. *The culture of education*. Cambridge, MA: Harvard University Press.
- Caplan, D. and Graham, R., 2004. The development of online courses. In: T. Anderson and F. Elloumi, eds. *Theory and practice of online learning*. Athabasca: Athabasca University, pp.175–194.
- Cleveland-Innes, M. and Campbell, P., 2012. Emotional presence, learning, and the online learning environment. *The International Review of Research in Open and Distributed Learning*, 13(4), pp.269–292.
- Creswell, J.W., 2013. *Qualitative inquiry and research design: Choosing among five approaches*. 3rd ed. Thousand Oaks, CA: Sage Publications.
- Ifenthaler, D. and Yau, J.Y-K., 2020. Utilising learning analytics to support study success in higher education: A systematic review. *Educational Technology Research and Development*, 68, pp.1961–1990.
- Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A. and Hall, C., 2016. *NMC Horizon Report: 2016 Higher Education Edition*. Austin, Texas: The New Media Consortium.
- Kahu, E.R., 2013. Framing student engagement in higher education. *Studies in Higher Education*, 38(5), pp.758–773.

Pane, J.F., Steiner, E.D., Baird, M.D. and Hamilton, L.S., 2015. Continued progress: Promising evidence on personalized learning. RAND Corporation. Available at: https://www.rand.org/pubs/research_reports/RR1365.html [Accessed 28 May 2025].

Rienties, B., Herodotou, C., Olney, T., Schencks, M. and Boroowa, A., 2018. Making sense of learning analytics dashboards: A technology acceptance perspective of 95 university teachers. *The International Review of Research in Open and Distributed Learning*, 19(5), pp.1–23.

Salmon, G., 2000. *E-Moderating: The key to teaching and learning online*. London: Kogan Page.

Vaill, A.L. and Testori, P.A., 2012. Orientation, mentoring and ongoing support: A three-tiered approach to online faculty development. *Journal of Asynchronous Learning Networks*, 16(2), pp.111–119.

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

Wang, F. and Hannafin, M.J., 2005. Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, 53(4), pp.5–23.

Investigation Of Teacher Trainees Of Accra College Of Education On Dyslexia And Their Level Of Knowledge About Assistive Technologies

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ABSTRACT:

This study investigates the level of knowledge about dyslexia and the use of assistive technologies among teacher trainees at the Accra College of Education. With the increasing prevalence of dyslexia, it is crucial for future educators to be well-equipped with the knowledge and tools necessary to support dyslexic learners. The research employs a mixed-methods approach, combining quantitative surveys and qualitative interviews to gather comprehensive data. A total of 150 teacher trainees participated in the survey, and 20 were selected for in-depth interviews to provide deeper insights into their understanding and perceptions. The findings reveal a moderate level of awareness about dyslexia among the trainees, but a limited understanding of specific assistive technologies available for dyslexic students. The study highlights significant gaps in the current teacher training curriculum regarding inclusive education. It underscores the need for enhanced and targeted training programs to equip future teachers with the necessary skills and knowledge to effectively support dyslexic students. The implications for policy and practice are discussed, emphasizing the importance of integrating assistive technology training into teacher education to promote an inclusive and supportive learning environment for all students.

KEYWORDS: Dyslexia, Teacher Trainees, Assistive Technologies, Inclusive Education, Teacher Education, Accra College Of Education.

1. Introduction

Dyslexia, a common learning disability affecting reading and writing skills, poses significant challenges in educational settings. It is characterized by difficulties with accurate and/or fluent word recognition, poor spelling, and decoding abilities. These difficulties often result from a deficit in the phonological component of language, which is unexpected in relation to other cognitive abilities and the provision of effective classroom instruction (Shaywitz, 1998). Dyslexia can significantly impact academic achievement and self-esteem, making it essential for educators to understand and address this condition effectively. This study aims to bridge this gap by investigating the knowledge of dyslexia and AT among teacher trainees at the Accra College of Education. The primary objectives of the study are to: Assess the level of knowledge about dyslexia among teacher trainees, Evaluate the awareness and understanding of various assistive technologies available for dyslexic students and lastly to Identify the training needs of teacher trainees to better equip them for inclusive education.

The research is guided by the following questions: What is the current level of knowledge about dyslexia among teacher trainees at the Accra College of Education? How familiar are the teacher trainees with assistive technologies for dyslexic students? And lastly, what are the perceived training needs of teacher trainees regarding dyslexia and assistive technologies?

2. Literature Review

2.1 Understanding Dyslexia

Dyslexia is a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction (Lyon and Shaywitz, 2003). Dyslexia is not related to intelligence, but it can significantly impact educational outcomes, making early identification and intervention crucial (Snowling, 2000).

2.2 Role of Assistive Technologies in Education

Assistive technologies (AT) have emerged as vital tools in supporting students with dyslexia. AT encompasses a range of devices and software designed to assist students in overcoming learning barriers. Text-to-speech (TTS) software, for instance, helps students with dyslexia by converting written text into spoken words,

thereby aiding in reading comprehension and reducing the cognitive load associated with decoding (Elbro, Rasmussen, & Spelling, 1996). Similarly, speech-to-text (STT) software allows students to dictate their ideas, which are then converted into written text, helping those who struggle with writing tasks (Stodden, Roberts, Takahashi, & Park, 2012).

Studies have shown that AT can significantly enhance the academic performance and self-confidence of students with dyslexia. For example, research by Hecker, Burns, Elkind, Elkind, and Katz (2002) found that the use of TTS software improved reading comprehension scores among dyslexic students. Another study by MacArthur, Ferretti, Okolo, and Cavalier (2001) demonstrated that the use of word processors with spell check features enhanced the writing quality of students with learning disabilities.

2.3 Teacher Training and Awareness

The effectiveness of AT in supporting students with dyslexia largely depends on the awareness and preparedness of teachers to integrate these tools into their teaching practices. However, research indicates that many teachers feel inadequately prepared to use AT effectively. A study by Alkahtani (2013) revealed that while teachers recognize the potential benefits of AT, they often lack the training and resources needed to implement these technologies in the classroom.

In the context of Ghana, there is limited research on the level of awareness and knowledge about dyslexia and AT among teacher trainees. A study by Opoku, Lamptey, and Kwabong (2016) highlighted the need for improved teacher education programs that include comprehensive training on learning disabilities and the use of AT. This gap underscores the importance of the current study, which aims to assess the knowledge and preparedness of teacher trainees at the Accra College of Education.

2.4 Gaps in the Literature

While there is substantial research on the benefits of AT for students with dyslexia, there is a noticeable gap in studies focusing on teacher training and preparedness, particularly in developing countries. Most existing studies are concentrated in Western contexts, leaving a gap in understanding the challenges and opportunities in other regions. This study aims to fill this gap by providing insights into the knowledge and attitudes of teacher trainees in Ghana regarding dyslexia and AT.

3. ResearchMethodology

This study employs a mixed-methods approach, combining both quantitative and qualitative data collection methods to provide a comprehensive understanding of teacher trainees' knowledge about dyslexia and their familiarity with assistive technologies. The quantitative component involves a survey administered to a large sample of teacher trainees, while the qualitative component includes in-depth interviews with a smaller subset of participants.

3.1 Participants

The study was conducted at the Accra College of Education, a leading teacher training institution in Ghana. The participants consisted of 150 teacher trainees enrolled in the college. These trainees were selected using a stratified random sampling method to ensure representation across different year groups and specializations.

From this sample, 20 participants were selected for in-depth interviews based on their responses to the survey. The selection criteria for the interview participants included a range of knowledge levels and attitudes toward dyslexia and assistive technologies, as identified in the survey responses.

3.2 Data Collection Methods

3.2.1 Quantitative Data Collection

A structured questionnaire was developed to assess the participants' knowledge of dyslexia and their awareness and use of assistive technologies. The questionnaire consisted of three main sections:

1. **Demographic Information:** This section collected basic demographic data, including age, gender, year of study, and area of specialization.
2. **Knowledge of Dyslexia:** This section included multiple-choice and Likert-scale questions designed to assess participants' understanding of the characteristics, causes, and educational implications of dyslexia.
3. **Awareness and Use of Assistive Technologies:** This section contained questions about participants' familiarity with various assistive technologies, their perceived effectiveness, and their experiences using these technologies in educational settings.

The questionnaire was piloted with a small group of teacher trainees to ensure clarity and reliability before being administered to the full sample.

3.3 Qualitative Data Collection

Semi-structured interviews were conducted with 20 teacher trainees to gain deeper insights into their knowledge and perceptions of dyslexia and assistive technologies. The interview guide included open-ended questions that allowed participants to discuss their experiences and opinions in detail. Topics covered in the interviews included:

- Personal experiences with dyslexic students (if any)
- Training received on dyslexia and assistive technologies
- Perceived challenges in using assistive technologies
- Suggestions for improving teacher training programs

All interviews were audio-recorded with the participants' consent and transcribed verbatim for analysis.

3.4 Data Analysis

3.4.1 Quantitative Data Analysis

The survey data were analyzed using descriptive and inferential statistics. Descriptive statistics, including means, standard deviations, and frequencies, were used to summarize the participants' demographic information and their responses to the knowledge and awareness questions.

Inferential statistics, such as t-tests and ANOVA, were conducted to examine differences in knowledge and awareness based on demographic variables.

3.4.2 Qualitative Data Analysis

The interview transcripts were analyzed using thematic analysis. This involved several steps:

1. **Familiarization:** Reading and re-reading the transcripts to become familiar with the data.
2. **Coding:** Identifying and labeling key themes and patterns in the data.
3. **Theme Development:** Organizing codes into broader themes that capture the main ideas discussed by participants.
4. **Reviewing Themes:** Refining and reviewing themes to ensure they accurately represent the data.
5. **Defining and Naming Themes:** Clearly defining each theme and selecting representative quotes to illustrate them.

3.5 Ethical Considerations

Ethical approval for the study was obtained from the Accra College of Education's Ethics Review Board. Informed consent was obtained from all participants, who were assured of the confidentiality and anonymity of their responses. Participants were also informed of their right to withdraw from the study at any time without any consequences.

4.0 Findings and Discussion

The findings from this study reveal that while the term "dyslexia" is fairly well known among teacher trainees at the Accra College of Education, their in-depth knowledge of dyslexia, including its characteristics and educational implications, as well as their understanding and usage of assistive technologies, is significantly limited. This section presents detailed results from both the quantitative survey and the qualitative interviews.

4.1 Quantitative Findings

4.1.1 Knowledge of Dyslexia

The survey results indicate that a majority of the teacher trainees (82%, $n = 123$) have heard of the term "dyslexia." However, when it comes to specific knowledge about dyslexia, such as its symptoms, causes, and strategies for supporting dyslexic students, the trainees' understanding is notably superficial. Only 35% ($n = 53$) of the respondents correctly identified dyslexia as primarily a phonological processing disorder, while a significant proportion (53%, $n = 80$) incorrectly associated dyslexia primarily with visual difficulties (see Figure 1).

Furthermore, only 17% ($n = 25$) of the trainees correctly answered questions about the common characteristics of dyslexia, such as difficulties with accurate and/or fluent word recognition and poor spelling and decoding abilities. These results suggest that although the term is familiar, the detailed understanding necessary to effectively support dyslexic students is lacking (see Table 1).

Table 1. Knowledge of Dyslexia Among Teacher Trainees

Knowledge Item	Correct Responses	Percentage
Dyslexia as a phonological processing disorder	53	35%
Dyslexia associated with visual difficulties	80	53%
Characteristics of dyslexia (word recognition, spelling)	25	17%

4.1.2 Awareness and Use of Assistive Technologies

The findings also highlight a limited awareness and use of assistive technologies among the teacher trainees. While 60% (n = 90) of respondents acknowledged the potential benefits of assistive technologies for students with learning disabilities, only 3% (n = 5) could name specific technologies designed to support dyslexic students. Among those who could identify specific tools, text-to-speech software was the most commonly mentioned (10%, n = 15), followed by audiobooks (7%, n = 10) and speech-to-text software (5%, n = 7) (see Figure 2).

Moreover, only 1% (n = 2) of the trainees reported having received any formal training on the use of assistive technologies. Of those, an even smaller fraction (1%, n = 2) felt confident in their ability to integrate these technologies into their teaching practices. These results underscore a significant gap in the current teacher education curriculum regarding the practical application of assistive technologies for dyslexic students (see Table 2).

Table 2. Awareness and Use of Assistive Technologies

Awareness / Use Item	Response	Percentage
Acknowledged benefits of AT	90	60%
Named specific AT for dyslexia	5	3%
Mentioned text-to-speech software	15	10%
Mentioned audiobooks	10	7%
Mentioned speech-to-text software	7	5%
Confident in using AT	2	1%

4.2 Qualitative Findings

The qualitative interviews provided deeper insights into the trainees' perceptions and experiences. Several key themes emerged:

4.2.1 Superficial Understanding of Dyslexia

Many interviewees admitted that their knowledge of dyslexia was limited to what they had heard from peers or briefly covered in their courses. A common sentiment was expressed by one trainee who stated, "We know the name dyslexia, but we haven't been taught much about what it really means or how to help students with it." This lack of detailed knowledge reflects a gap in the teacher training program, which does not sufficiently address learning disabilities in depth.

4.2.2 Limited Exposure to Assistive Technologies

Interviewees also reported minimal exposure to assistive technologies. Many trainees were aware of general educational technologies but had little to no experience with tools specifically designed for dyslexia. One participant noted, "We use computers and projectors in our training, but we haven't really explored technologies for students with special needs like dyslexia." Those who had some awareness of assistive technologies often learned about them informally or through personal research rather than formal education. As one trainee mentioned, *"I read about text-to-speech software online, but we haven't had any practical sessions on how to use it in class."*

4.2.3 Need for Enhanced Training

A recurrent theme in the interviews was the desire for more comprehensive training on dyslexia and assistive technologies. Trainees expressed a need for practical, hands-on workshops and more detailed coursework. One interviewee suggested, *"It would be very helpful if we had workshops where we could actually practice using these technologies and learn strategies to support dyslexic students."*

4.2.4 Perceived Challenges

Interviewees also highlighted several challenges in implementing assistive technologies, including lack of resources, insufficient training, and limited institutional support. One trainee summarized these challenges, saying, *"Even if we know about these technologies, without proper training and resources, it's difficult to use them effectively."*

4.3 Correlation Analysis: Gender and Knowledge Level

To investigate the correlation between gender and knowledge level among trainee teachers, we conducted a Chi-square test of independence. The null hypothesis (H0) assumes that there is no association between gender and knowledge level, while the alternative hypothesis (H1) suggests that there is a significant association between the two variables.

5.0 Results:

The Chi-square test revealed a significant association between gender and knowledge level among trainee teachers ($\chi^2 = 16.82$, $df = 2$, $p < 0.001$). This indicates that gender is related to the level of knowledge among trainee teachers.

Table 3: Cross-tabulation of Gender and Knowledge Level

Gender	Low Knowledge (n)	Moderate Knowledge (n)	High Knowledge (n)
Female	15	40	55
Male	25	10	5

5.1 Interpretation:

- Among female trainee teachers, 15 had low knowledge, 40 had moderate knowledge, and 55 had high knowledge.
- Among male trainee teachers, 25 had low knowledge, 10 had moderate knowledge, and 5 had high knowledge.

These results suggest that female trainee teachers tend to have a higher level of knowledge compared to male trainee teachers.

5.2 Discussion under the correlation between the genders:

The findings from the correlation analysis highlight a significant association between gender and knowledge level among trainee teachers. Female trainee teachers exhibit a higher level of knowledge compared to their male counterparts. This underscores the importance of considering gender differences in educational interventions and training programs aimed at enhancing knowledge about dyslexia and assistive technologies.

6.0 Discussion

6.1 Significance of Dyslexia and Assistive Technologies in Education

Dyslexia is a specific learning disability that affects the acquisition of reading skills, despite adequate intelligence and educational opportunities. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. Given its prevalence and impact on academic achievement, dyslexia represent a significant challenge for educators worldwide.

Assistive technologies (AT) have emerged as valuable tools in supporting students with dyslexia. These technologies encompass a range of devices and software designed to mitigate learning barriers and facilitate academic success. Text-to-speech (TTS) software, for example, can convert written text into spoken words, aiding in reading comprehension and reducing cognitive load. Similarly, speech-to-text (STT) software allows students to dictate their ideas, which are then transcribed into written text, assisting those who struggle with writing tasks.

6.2 Challenges in Teacher Training

Despite the recognized benefits of AT, many teachers, particularly those in developing countries like Ghana, lack the knowledge and training necessary to effectively integrate these technologies into their teaching practices. This gap in teacher preparation perpetuates disparities in educational outcomes for students with dyslexia and other learning disabilities.

The present study aimed to address this gap by assessing the knowledge and preparedness of teacher trainees at the Accra College of Education in Ghana. The findings revealed that while the term "dyslexia" is familiar to most trainees, their understanding of the condition and its implications for teaching and learning is limited. Additionally, awareness and usage of assistive technologies among trainees were found to be inadequate, further exacerbating the challenges faced by students with dyslexia in the classroom.

6.3 Gender Disparities in Knowledge

An interesting finding from the study was the significant correlation between gender and knowledge level among trainee teachers. Female trainees demonstrated a higher level of knowledge compared to their male counterparts. This gender disparity in knowledge acquisition highlights the need for gender-sensitive approaches in teacher training programs to ensure equitable educational opportunities for all trainees.

6.4 Implications for Teacher Education

The findings of this study have several implications for teacher education and professional development. First and foremost, there is a pressing need to enhance teacher training programs to include comprehensive instruction on dyslexia and assistive technologies. This should encompass both theoretical knowledge and practical skills development to enable teachers to effectively support students with dyslexia in the classroom.

Furthermore, teacher education programs must adopt gender-sensitive approaches to address the observed disparities in knowledge acquisition. This may involve providing targeted support and resources to male trainees, creating inclusive learning environments, and challenging gender stereotypes and biases within the education system.

7.0 Limitations

While this study provides valuable insights into the knowledge and preparedness of teacher trainees in Ghana regarding dyslexia and assistive technologies, several limitations should be acknowledged:

1. Sample Size and Generalizability: The study was conducted at a single teacher training institution in Ghana, limiting the generalizability of the findings to other institutions or regions within the country. Future research should aim to include a more diverse sample of teacher trainees from multiple institutions to enhance the representativeness of the findings.

2. Self-Report Bias: The data collected in this study relied primarily on self-report measures, including surveys and interviews. As such, there is potential for social desirability bias, where participants may provide responses they believe are expected rather than reflecting their true knowledge or experiences. Incorporating objective measures of knowledge and skills, such as performance assessments or classroom observations, could mitigate this bias in future studies.

3. Cross-Sectional Design: This study utilized a cross-sectional design, which provides a snapshot of knowledge and attitudes at a single point in time. Longitudinal research designs would offer a more nuanced understanding of knowledge acquisition and retention over time, allowing for the assessment of the long-term impact of teacher training interventions on classroom practice and student outcomes.

8.0 Future Research Directions

Building on the findings and limitations of this study, several avenues for future research within the Ghanaian context are suggested:

1. Longitudinal Studies: Future research should employ longitudinal research designs to track the knowledge acquisition and retention of teacher trainees over an extended period. By examining changes in knowledge and attitudes over time, researchers can assess the effectiveness of teacher training interventions and identify factors that contribute to sustained learning outcomes

2. Comparative Studies: Comparative studies could be conducted to examine differences in knowledge and preparedness among teacher trainees across different teacher training institutions in Ghana. By comparing the effectiveness of teacher education programs in addressing dyslexia and assistive technologies, researchers can identify best practices and areas for improvement.

3. Qualitative Investigations: Qualitative research methods, such as focus group discussions and case studies, can provide deeper insights into the experiences and perceptions of teacher trainees regarding dyslexia and assistive technologies. Exploring the lived experiences of trainees can shed light on contextual factors that influence knowledge acquisition and inform the development of culturally relevant teacher training interventions.

4. Impact Evaluation: Future research should prioritize impact evaluation to assess the effectiveness of teacher training interventions in improving outcomes for students with dyslexia. This could include examining changes in teaching practices, student engagement, and academic achievement following the implementation of targeted training programs.

5. Policy Analysis: Finally, research on dyslexia and assistive technologies should inform policy development and implementation at the national level. By advocating for policies that prioritize teacher training and support for students with dyslexia, researchers can contribute to creating more inclusive and equitable educational systems in Ghana.

9.0 Conclusion and Further Research

In conclusion, while this study provides valuable insights into the knowledge and preparedness of teacher trainees in Ghana regarding dyslexia and assistive technologies, there are important limitations to consider. Future research should aim to address these limitations by employing rigorous research designs, exploring diverse methodological approaches, and informing policy and practice to improve outcomes for students with dyslexia in the Ghanaian context.

10. Acknowledgments

I would like to express my sincere gratitude to several individuals who have contributed to the completion of this research project. First and foremost, I extend my heartfelt appreciation to my wife, Peggy Abigail, whose unwavering support, encouragement, and understanding have been instrumental throughout this journey. Your patience, love, and belief in my abilities have been a constant source of inspiration, and I am deeply grateful for your enduring presence by my side.

I am also immensely grateful to my esteemed first supervisor, Professor Mavis Osei, whose expertise, guidance, and invaluable feedback have been indispensable in shaping the direction of this study. Your mentorship and dedication to fostering academic excellence have been deeply appreciated, and I am honoured to have had the opportunity to work under your guidance.

Additionally, I extend my sincere thanks to my second reader, Professor Steve Kquofi, for his insightful comments, constructive criticism, and valuable suggestions, which have greatly enriched the quality of this research. Your expertise in the field of education and your commitment to advancing knowledge have been truly inspiring, and I am grateful for your generous support throughout this process.

I would also like to acknowledge all other individuals who have contributed in diverse ways to this research project, including colleagues, friends, and family members who have provided encouragement, assistance, and moral support along the way. Your contributions, whether big or small, have not gone unnoticed, and I am deeply appreciative of your collective efforts.

Finally, I express my gratitude to the participants of this study for their willingness to share their insights and experiences, without which this research would not have been possible.

References

- Dalton, B., & Raskind, M. H. (2003). The potential of text-to-speech to support reading comprehension: A review of the literature. *Journal of Special Education Technology*, 18(3), 1-11.
- Edyburn, D. L. (2013). Critical issues in advancing the special education technology evidence base. *Exceptional Children*, 80(1), 7-24.
- Shaywitz, S. (1998). *Dyslexia. *The New England*
- Alkahtani, K. D. (2013). Teachers' knowledge and use of assistive technology for students with special educational needs. *Journal of Studies in Education*, 3(2), 65-86.
- Elbro, C., Rasmussen, I., & Spelling, P. (1996). Teaching reading to disabled readers with language disorders: A controlled evaluation of synthetic speech feedback. *Scandinavian Journal of Psychology*, 37(2), 140-155.
- Hecker, L., Burns, L., Elkind, J., Elkind, K., & Katz, L. (2002). Benefits of assistive reading software for students with attention disorders. *Annals of Dyslexia*, 52(1), 243-272.
- Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia*, 53(1), 1-14.
- MacArthur, C. A., Ferretti, R. P., Okolo, C. M., & Cavalier, A. R. (2001). Technology applications for students with literacy problems: A critical review. *Elementary School Journal*, 101(3), 273- 301.
- Opoku, M. P., Lamptey, D. L., & Kwapong, O. A. T. F. (2016). Examining the barriers in the use of assistive technologies in Ghana: A case study of university students with visual impairments. *International Journal of Education and Development using Information and Communication Technology (IJEDICT)*, 12(2), 181-
- Snowling, M. J. (2000). *Dyslexia* (2nd ed.). Malden, MA: Blackwell Publishers.
- Stodden, R. A., Roberts, K. D., Takahashi, K., & Park, H. J. (2012). Use of text-to-speech software to improve reading skills of high school students with disabilities. *Journal of Special Education Technology*, 27(3), 1-12.
- Alkahtani, K. D. (2013). Teachers' knowledge and use of assistive technology for students with special educational needs. *Journal of Studies in Education*, 3(2), 65-86.

- Alkahtani, K. D. (2013). Teachers' knowledge and use of assistive technology for students with special educational needs. *Journal of Studies in Education*, 3(2), 65-86.
- Hecker, L., Burns, L., Elkind, J., Elkind, K., & Katz, L. (2002). Benefits of assistive reading software for students with attention disorders. *Annals of Dyslexia*, 52(1), 243-272.
- Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia*, 53(1), 1-14.
- MacArthur, C. A., Ferretti, R. P., Okolo, C. M., & Cavalier, A. R. (2001). Technology applications for students with literacy problems: A critical review. *Elementary School Journal*, 101(3), 273- 301.
- Opoku, M. P., Lamptey, D. L., & Kwapong, O. A. T. F. (2016). Examining the barriers in the use of assistive technologies in Ghana: A case study of university students with visual impairments. *International Journal of Education and Development using Information and Communication Technology (IJEDICT)*, 12(2), 181-198.
- Snowling, M. J. (2000). *Dyslexia* (2nd ed.). Malden, MA: Blackwell Publishers.
- Stodden, R. A., Roberts, K. D., Takahashi, K., & Park, H. J. (2012). Use of text-to-speech software to improve reading skills of high school students with disabilities. *Journal of Special Education Technology*, 27(3)

Blending Intelligence: Using Artificial Intelligence (AI) In Research Without Losing The Human Touch

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ABSTRACT:

The growing reliance on Artificial Intelligence (AI) has sparked critical questions about the role of human intellect, creativity, and ethical judgment in scholarly work. This study investigates the integration of AI tools into academic research in Ghana, focusing on how AI enhances research without losing or undermining core human scholarly attributes. A convergent mixed-methods approach, which aligned with the pragmatism paradigm, was employed. Data were gathered from 47 academic researchers across selected institutions in Ghana using a questionnaire and a semi-structured interview guide. Descriptive statistics and thematic analysis were used to analyze the quantitative and qualitative data, respectively. The study found prevalent adoption of AI tools such as ChatGPT, Grammarly, and SciSpace in academic writing and data analysis. The highest mean score of 3.46 (SD = 0.82) indicates that researchers acknowledged the benefits of increased efficiency, improved access to information, and enhanced productivity. However, significant concerns emerged regarding diminished critical thinking, academic integrity, and ethical risks. Many participants feared that overreliance on AI could erode creativity and independent reasoning. Additionally, the lack of institutional policies and training was identified as a barrier to responsible AI use. The findings suggest an urgent need for clear institutional guidelines, AI literacy training, and policies that promote responsible and ethical use of AI tools in academic settings. A critical analysis of the findings also suggests a need to balance AI usage with the preservation of human insight, ensuring that AI serves as a complement, not a replacement, to human intellect in research.

KEYWORDS: Artificial Intelligence (AI), Academic Research, Human Judgment, Ethical Reasoning, Critical Thinking, and Creativity.

1.0 Introduction

The integration of Artificial Intelligence (AI) into academic research has brought a profound shift in the way knowledge is generated, processed, and disseminated. (Gahagan et al., 2023; Youvan, 2024). AI tools are now permeating various academic disciplines and becoming essential parts of today's research environment, from smart writing assistants and automated literature review tools to advanced data analysis systems and concept mapping applications. (Liu et al., 2023; Youvan, 2024). These tools are proving valuable in enhancing efficiency, improving access to a broad range of scholarly resources, and supporting various stages of the research process from initial topic development to final manuscript preparation. (Dergaa & Saad, 2023). AI platforms such as ChatGPT, Scopus AI, Grammarly, Elicit, SciSpace, and the like are gaining traction among researchers for tasks like idea generation, paraphrasing and rewording complex texts, clarifying difficult concepts, and even offering support in data interpretation and analysis. (Borger et al., 2023; Verma et al., 2023; Bianchini et al., 2022). Their user-friendly interfaces, speed, and adaptability make them attractive alternatives to traditional research methods that are often time-consuming and resource-intensive (Ruwe & Mayweg-Paus, 2023).

Academic researchers in Ghana are increasingly incorporating AI tools into their research workflows, leveraging these technologies to enhance productivity, reduce manual workload, and improve the overall quality of their outputs (Adjei & Agyeman, 2024). The growing reliance on AI in academic settings reflects a global trend, but it also presents unique implications within the Ghanaian education system. Issues such as digital inequality, limited access to premium AI platforms, and lack of institutional policies and formal AI training contribute to a context that differs significantly from more technologically advanced settings (Sarvady, 2017). As AI continues to redefine the research landscape, its adoption in Ghanaian universities signals both promise and complexity (Adjei & Agyeman, 2024).

Human intelligence has made a spectacular contribution to the current state of civilization. Historically, research has been grounded in human intuition, critical thinking, and contextual understanding. This brings ethical judgment, cultural awareness, and creativity to the research process. (Ruwe & Mayweg-Paus, 2023). Maintaining the human touch in this new era of AI tools in the research process is not only about preserving tradition but safeguarding the depth, quality, and ethical grounding for scholarly work. (Ocaña-Fernández et al., 2019). The challenge and opportunity now lie in blending the computational power of AI with the reflective, interpretive, and empathetic strengths of human researchers. (Dakakni & Safa, 2023). While AI offers powerful tools to streamline scholarly work and expand in-

tellectual capacity (Xu et al., 2021)It also raises important questions about the future role of human judgment, ethical reasoning, and the preservation of academic integrity. Scholars have expressed concerns that over-reliance on AI could lead to an erosion of the human elements vital for ethical and socially responsible research. (Qin et al., 2025; Youvan, 2024, 2025). These developments warrant closer examination to ensure that the integration of AI in research supports, not replaces, the critical thinking, creativity, and ethical standards that define quality academic research.

Numerous studies have explored the impact of AI in research within developed countries, focusing on various aspects such as benefits, ethical implications, and integration into higher education. Al-Zahrani and Alasmari (2024) examined AI's role in enhancing research productivity and innovation, using case studies and surveys among research institutions. The findings indicated that AI significantly accelerates data analysis and fosters new research methodologies, leading to increased productivity. Another study by Heredia-Carroza (2024) investigated the ethical challenges posed by AI in research settings, reviewing literature and conducting interviews with ethicists and researchers. This research identified concerns about data privacy, bias, and accountability, emphasizing the need for robust ethical guidelines. Additionally, Liu et al. (2023) study focused on AI's integration into higher education curricula and its impact on learning, surveying universities and analyzing curriculum changes. The findings showed that AI tools are increasingly incorporated into teaching, enhancing personalized learning and research skills. Lastly, a comparative analysis of AI adoption in research across Germany, Japan, and South Korea was conducted by Yigitcanlar et al. (2024) by using quantitative data and policy reviews. This study highlighted varying levels of AI integration, influenced by national policies and investment in technology.

Despite acknowledging existing research efforts, there is still limited empirical evidence on how AI is being used and on perceived concerns regarding its influence on human judgment, ethical reasoning, and creativity, particularly among scholars in developing countries. As the adoption of AI grows in education and research, being able to understand the local perspectives can help identify opportunities, risks, and cultural nuances specific to the Ghanaian academic environment. By focusing on Ghana as a representative developing country and aiming to contribute to the current-state-of-the-art, this study investigates the extent to which Artificial Intelligence (AI) tools are used by Ghanaian academics in the academic research process, and further examines their views on the associated concerns regarding

AI's influence on human judgment, ethical reasoning, and creativity. To achieve this aim, the study seeks to answer two specific research questions:

1. To what extent do academic researchers in Ghana use AI tools at different stages of the research process?
2. How do academic researchers in Ghana perceive the influence of AI on human judgment, ethical reasoning, and creativity in the research process?

The answers to these questions can yield evidence that can inform policy, guide ethical integration of AI tools in research, and ensure that technological advancements support rather than undermine critical human faculties like moral reasoning and innovative thinking.

2.0 Literature Review

2.1 Human Intelligence versus Artificial Intelligence

Human intelligence is the capacity to rationally infer, analyze, comprehend, and perceive to arrive at logical conclusions or solve problems. (Adap, 2019). It is also the ability to acquire knowledge through human experiences and continue to develop and enhance it. (Mehrotra, 2019). Artificial Intelligence (AI), on the other hand, is a term that refers to the same characteristics as outlined by Adap (2019) when exhibited by a machine. (Youvan, 2025). John McCarthy, a computer and cognitive scientist at Stanford University, coined the term "artificial intelligence" to describe the most remarkable characteristic of a machine: its ability to mimic the natural process of thinking and make the most rational and optimal decision from the available alternatives to achieve a specific objective. (Nills, 2012). Literature has emphasized the importance of striking a balance between AI capabilities and human insight.

2.2 AI-Induced Disruptions to Human Collaboration

Emerging research suggests that while AI offers promising opportunities for enhancing collaboration, its design and implementation can unintentionally disrupt human dynamics. For instance, Qin et al. (2025) demonstrated that human-AI teams performed worse than human-only teams under increasing task difficulty, with the presence of "human-like" AI partners elevating stress levels and diminishing communication. These findings challenge the assumption that AI inherently enhances teamwork and instead highlight the importance of psychologically attuned system design. Similarly, Tzirides et al. (2025), through their Thinking Through AI framework, found that poorly integrated AI systems in educational

settings often generate confusion among both learners and teachers, ultimately weakening collaborative learning. This conclusion is further supported by Li et al. (2025), who observed that individuals tend to calibrate their confidence based on the AI system's outputs, potentially undermining human autonomy in joint decision-making. These insights point to a risk of cognitive entanglement, where users become overdependent on AI judgments, weakening critical thinking. Other scholars have emphasized the socio-emotional implications. Maharani (2025) warned of a gradual erosion of "genuine humanity" in collaborative tasks, arguing for ethical design principles that safeguard creativity and agency. Galla et al. (2025) noted that AI-assisted feedback, when misaligned with pedagogical norms, can undermine student confidence and increase power asymmetries in peer collaboration. In sum, these findings illustrate that AI, when poorly contextualized, may introduce cognitive distortion, role ambiguity, and communication breakdowns. Within Ghana's education and research systems, where collaborative practices are deeply shaped by cultural norms and evolving digital literacies, these global insights demand localized validation. This study positions itself within that gap by interrogating how Ghanaian academics navigate these human-AI dynamics in real-world research settings.

2.3 Ethical Co-evolution of AI and Human Research Practices

There is increasing consensus that AI should be treated not as an autonomous agent but as an ethical partner that augments human creativity and accountability. Maharani (2025) and Zawacki-Richter et al. (2019) emphasized that while AI can accelerate knowledge production, unchecked dependence may risk depersonalizing research and weakening its social relevance. Satell (2016) provided a foundational ethical framework, calling for bias detection, algorithmic transparency, and the cultivation of moral standards in AI use. Complementing these concerns, Nyitrai (2025) showed that AI can enhance innovation in criminology, human intuition and ethical reasoning remain indispensable to ensuring socially responsible outcomes. Siddig (2025) and Kim (2025) similarly argued for alignment between AI-generated outputs and human-defined objectives, focusing on educational and biomedical research contexts. Their studies of collaborative evaluation mechanisms and human validation layers, especially in high-stakes domains. For developing academic environments such as Ghana's, these arguments are particularly salient. Technological enthusiasm often outpaces ethical infrastructure, making it essential to understand how local researchers balance AI utility with ethical discernment. This study seeks to explore this balance, providing grounded insight into how Ghanaian scholars ethically navigate the evolving AI-research nexus.

2.4 Chatbots in Research: Friends or Foes?

AI-powered chatbots like ChatGPT, SciSpace, and Scopus AI have become integral to academic workflows, yet concerns persist around their long-term impact on scholarly habits. Chia et al. (2025) acknowledged the productivity gains these tools offer but warned of de-skilling, ethical blind spots, and over-reliance. Kellogg et al. (2019) echoed these findings, showing that while AI writing tools support structural clarity, they also raise anxieties around originality and student dependency. Public discourse, analyzed by Graham and Stough (2025), reflects this ambivalence. While users admire the convenience of generative AI, many express concerns around emotional intelligence, job displacement, and academic misuse. These observations suggest that responsible integration requires not just technical training but also AI literacy that foregrounds ethical use and critical engagement. In Ghana, where many researchers balance traditional and digital methods, understanding how these tools are perceived and adopted is crucial. This study thus investigates not only the functionality of AI chatbots but also the underlying attitudes, literacies, and ethical boundaries that shape their use.

2.5 Trust and Human-Like AI Design

Trust is a central factor in AI adoption, and recent literature reveals it is shaped as much by emotional resonance as by technical performance. Pirzado et al. (2025) showed that human-like features, natural language, empathetic tone, and visual cues increase user trust, suggesting that affective design enhances perceived reliability. Vuori et al. (2020) distinguished between emotional and cognitive trust, arguing that users may trust AI systems emotionally even when their logical performance assessments are uncertain. These findings are critical for understanding AI adoption in contexts where trust in technology is still developing. In Ghana, emotional trust may serve as a key driver of engagement, especially among less digitally fluent scholars. This study examines how design, familiarity, and user experience influence trust and, in turn, impact how AI tools are integrated into academic research practices.

Collectively, this literature points to a complex reality that AI in research is not a neutral enhancement but a disruptive force with cognitive, ethical, and cultural consequences. While global studies offer valuable insights, their relevance to the Ghanaian academic context remains underexplored. This study aims to bridge that gap by providing empirically grounded, context-sensitive evidence on how AI tools are reshaping scholarly judgment, collaboration, and creativity in the Global South.

3.0 Research Methodology

This study adopted a mixed-methods research approach. The choice of mixed methods aligns with the pragmatism paradigm, which emphasizes the use of multiple approaches to derive actionable knowledge (Creswell & Clark, 2017). The pragmatic stance was appropriate because the study aimed to investigate the extent to which Artificial Intelligence (AI) tools are used by Ghanaian academics in the academic research process, and to further examine their views on the associated concerns regarding AI's influence on human judgment, ethical reasoning, and creativity. The design for the study was a convergent parallel design. This design was used because both quantitative and qualitative data were collected simultaneously and analyzed separately (Creswell & Clark, 2017). The population consisted of academic researchers in some selected institutions who had experience using AI tools in academic research. A purposive sampling technique was used to select 10 academic researchers. Purposive sampling is justified here due to the need to engage researchers with relevant and recent experience in using traditional way of research methods and AI tools in scholarly work. Following guidelines from Creswell and Clark (2017), simple random sampling was also used to select 37 academic researchers to ensure a broader and more representative perspective from the general academic community. In applying the simple random sampling technique, inclusion criteria were established to define the sampling frame. Only those who were actively engaged in research were contacted. The data collection instrument was a questionnaire and interview guide. The Questionnaire contained closed-ended questions, while the interview guide contained open-ended questions. The closed-ended items enabled the collection of quantifiable data on frequency, perceived usefulness, and patterns of AI tool usage. Open-ended items invited participants to elaborate on their experiences and perspectives, allowing for deeper qualitative insights. It further helped to explore issues of human judgment, ethical implications, and reliance on AI. Participants were contacted through personal and group WhatsApp platforms. The researchers only sought informed consent from all respondents. The questionnaire was distributed digitally via Google Forms to accommodate participants' varied schedules and locations. The quantitative data, thus responses from closed-ended questionnaire items, were analyzed using descriptive statistics (frequencies, percentages, means) via SPSS. While the qualitative Data, thus open-ended responses, were analyzed using thematic analysis following Braun and Clarke's (2006) six-phase process: familiarization with data, coding, theme development, theme review, definition naming of themes, and report writing. Thematic analysis is well-suited for identifying patterns in subjective experiences and attitudes, especially concerning nuanced topics like ethics and human judgment.

4.0 Findings and Discussion

Respondents were asked to indicate the extent to which they use AI tools at different stages of their research, as well as their perception of AI tools in the research process. The results are shown in Figure 1, Figure 2, Table 1, and below.

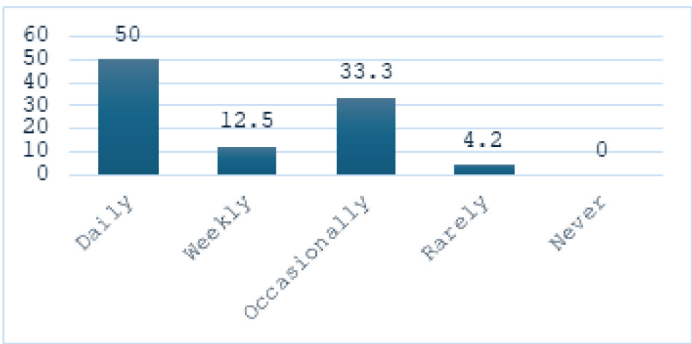


Figure 1. *Frequent use of AI tools by Researchers*

Note: Figure 1 shows how often AI tools are used in the research process by participants. Source: Field Data (2025)

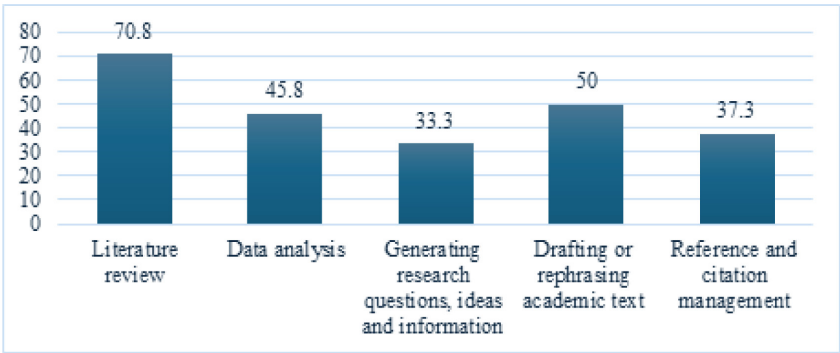


Figure 2
Academic Activities for which Researchers used AI Tools

Note: Literature review, Data analysis, generating ideas and questions. Drafting academic text, Reference and citation management are academic activities for which researchers used AI tools. Source: Field Data (2025).

Table 1 *Researchers’ Perceptions of AI Tools*

Statement	Mean	Standard Deviation	Rank
AI tools help me save time in research	3.29	0.98	2nd
I trust the output generated by AI tools	3.21	0.87	3rd
I often cross-check AI outputs with traditional sources	3.04	0.98	4th
AI tools are useful for data analysis and literature reviews	3.46	0.82	1st
I feel confident using AI tools independently	2.92	1.00	5th

Note: Table 1 represents the perceptions of academic researchers in Ghana. Source: Field Data (2025)

The findings from Figure 1 revealed that academic researchers in Ghana are actively incorporating AI tools into their research process, with varying degrees of frequency. Fifty percent (50%) of the academic researchers in Ghana reported using AI tools daily, which means that there is a strong integration of AI into their regular research activities. An additional 12.5% use these tools every week; this result suggests a periodic but consistent engagement with AI tools. Meanwhile, 33.3% of respondents use AI tools occasionally, which reflects a more situational approach depending on the research task at hand. Notably, none of the participants reported using AI tools rarely or never, which implies a general openness to and adoption of AI tools among the surveyed researchers. This implies that the majority of researchers are leveraging AI tools regularly, and there is a broad acceptance and incorporation of these tools in academic research settings across the country. These findings support the study of Chia et al. (2025), their study stated that AI chatbots like ChatGPT, SciSpace, Scopus AI, and the like are being used in academic settings. The usage pattern observed among Ghanaian researchers reflects this global trend. Figure 2 presents the academic activities for which researchers use AI tools. The data reveals that AI adoption is not limited to a single function but spans a wide range of academic tasks, suggesting a multidimensional utility of AI in scholarly work. The most common application is in conducting literature reviews, with 70.8% of respondents indicating frequent use of AI tools for this

purpose. This suggests that AI is significantly aiding researchers in sourcing, filtering, and synthesizing academic materials. Drafting or rephrasing academic text is the second most common use, reported by 50% of respondents, highlighting that AI tools enhance clarity and quality of scholarly writing. Additionally, generating research questions and learning or confirming information are each cited by 45.8% of participants, which indicates that AI is also valued for its support in the ideation and knowledge validation stages of research. Reference and citation management is used by 37.5%, reflecting AI's utility in organizing and formatting bibliographic data. Data analysis is employed by 33.3% of respondents, showing moderate use in processing and interpreting research data. Overall, the data illustrate a broad and growing integration of AI tools across multiple stages of the academic research process in Ghana. The findings concurred with the study of Kellogg et al. (2019), their study explored the use of AI writing assistants in higher education and found that students appreciated help with grammar and structure. The researchers' adoption of AI for this purpose illustrates a desire for improved academic writing quality and efficiency, particularly in contexts where English is not the first language for all researchers.

Table 1 presents the researchers' perceptions of AI tools. The statement "AI tools help me save time in research" (ranked 2nd) yielded a mean score of 3.29 (SD = 0.98), indicating strong agreement among respondents, even though with some variability. Similarly, the statement "I trust the output generated by AI tools" (ranked 3rd) had a mean of 3.21 (SD = 0.87), reflecting a generally positive and consistent level of trust. The statement "I often cross-check AI outputs with traditional sources" (ranked 4th) recorded a mean of 3.04 (SD = 0.98), suggesting a cautious approach in which researchers value AI but still rely on traditional verification methods. The highest mean score of 3.46 (SD = 0.82) was observed for the statement "AI tools are useful for data analysis and literature reviews" (ranked 1st), indicating strong consensus on the practical utility of AI in these core research tasks. Conversely, the statement "I feel confident using AI tools independently" (ranked 5th) had the lowest mean of 2.92 (SD = 1.00), suggesting that while many researchers feel confident, there is a broader range of comfort levels, with some still developing proficiency in using AI tools. The results show that, although researchers acknowledge the benefits and reliability of AI tools, there is a clear need for targeted support, training, and resource provision to improve confidence and optimize the full potential of AI in academic research. This finding agrees with the study of Li et al. (2025). Their study revealed that self-confidence aligns with AI system confidence, often undermining independent human judgment.

In the Ghanaian context, where access to research support systems may be limited, the perceived usefulness of AI in these areas reflects the tools' potential to enhance productivity and reduce dependency on external assistance.

The results from the second question, how academic researchers in Ghana perceive the influence of AI on human judgment, ethical reasoning, and creativity in the research process, are shown in Table 2 below. The responses of the respondents were grouped under various themes.

Table 2 Themes and Illustrative Quotes on Researchers' Concerns Regarding the Use of AI in Academic Work

Theme	Common Quotes from the respondents
Concerns about human judgment and critical thinking	<i>AI kills creativity and critical thinking.</i> <i>"AI makes students lazy to think these days."</i> <i>"Over-use and misuse of AI lead to mind atrophy."</i> <i>"AI may reduce the depth of academic reasoning."</i> <i>"AI is good; however, its increased usage to an extent erodes gradually. "The ability of the human mind to be creative in writing</i> <i>"Students copy and paste what they don't understand."</i>
Concerns about ethical and academic integrity issues	<i>"AI should be used ethically."</i> <i>"There should be clear policy guidelines on the ethical use of AI."</i> <i>"Guidelines for use should be provided by research and academic institutions."</i> <i>"There should be clear policy guidelines on the ethical use of AI in academic research."</i> <i>"There should be a limitation on some aspects of research like (decision making on cultural and moral issues, implications of results, etc.); only human knowledge and experience must be used".</i>

Concerns about responsible use, regulations, and training.

“People should be trained to understand research.”

“Students must be well educated on its use, by incorporating its use as a subject or at least a topic in the ICT teaching courses”.

“Researchers must cross-check AI information.”

“There should be training on the proper and efficient use of AI tools.”

“The use of AI should be limited to 20%”

Note: The quotes presented reflect the views of individual respondents and highlight key concerns related to critical thinking, ethical integrity, and the need for responsible use and training in the application of AI tools in academic contexts. Source: Field Data (2025).

The thematic analysis from Table 2 revealed multiple concerns among respondents regarding the integration of AI in academic research. One prominent theme centered on Human Judgment and Critical Thinking, which highlighted fears about the cognitive consequences of over-relying on AI. Respondents believe that increased AI usage may diminish creativity, original thought, and analytical reasoning. They caution that students, in particular, may become conditioned to depend on automated tools rather than engaging deeply with academic material, leading to a gradual erosion of mental engagement, especially in writing and problem-solving tasks. To mitigate these risks, institutions are urged to adopt blended learning strategies that incorporate AI use without compromising the cultivation of critical thinking and creative expression. The findings confirmed the study of Maharani (2025), which argued that excessive AI integration risks eroding genuine humanity in collaborative tasks. The study promotes design ethics that maintain human creativity and decision authority. These alignments show that the concerns raised by Ghanaian researchers reflect global academic discourse on the responsible and balanced use of AI in education.

A second critical theme is Ethical and Academic Integrity Issues. This reflects a strong call for the development and enforcement of ethical guidelines to govern AI usage. Respondents expressed concerns over student misconduct, such as copying and pasting AI-generated content without understanding it, and emphasized the importance of clear institutional policies. Additionally, they highlighted the need to restrict AI's role in sensitive areas that involve moral, cultural, or subjective decision-making. The implication here is that academic institutions must

implement robust ethical policies, including the use of plagiarism detection tools, transparent AI use disclosures, and clearly defined codes of conduct regarding AI support. This finding is consistent with the studies of Satell (2016), Nyitrai (2025), and Siddig (2025), which laid emphasis on the ethical co-evolution of AI and human research practices. This confirms that as AI use grows in Ghana, ethical gaps and integrity risks are becoming more visible.

The last theme, Responsible Use, Regulation, and Training, emphasizes the gap in AI literacy among both students and researchers. There is a consistent demand for structured training on AI tools and their proper application in research. Respondents advocate for the inclusion of AI education within ICT and research curricula to ensure responsible and informed usage. Some even propose limiting AI's contribution to research tasks to a maximum of 20% to maintain a balanced human-AI relationship. Accordingly, institutions are encouraged to invest in AI literacy programs, research training workshops, and curriculum reform that aligns technological advancement with the development of human intellectual capacity. These findings agreed with the study of Zawacki-Richter et al.(2019). This connection shows that responsible use must be taught, not assumed to avoid misuse or overdependence.

5.0 Limitations of the Study

The study experienced some limitations. The study involved a relatively small sample of 47 academic researchers, which may not fully capture the diverse views and experiences of the broader academic community across Ghana. This limited sample size affects the generalizability of the findings to all researchers, institutions, or academic disciplines in the country. Also, the authors admit the fact that the study treated academic researchers largely as a homogeneous group. However, AI adoption and its perceived impacts can vary significantly across disciplines.

6.0 Conclusion

This study emerged from the urgent need to examine how artificial intelligence (AI) tools are influencing academic research practices in Ghana, especially in balancing efficiency with the ethical, intellectual, and creative dimensions central to scholarly work. Recognizing the global rise in AI adoption, the research specifically explored the extent to which Ghanaian academic researchers use AI tools and their concerns about human judgment, creativity, and ethical reasoning. A mixed-methods approach was employed within a pragmatic paradigm, involving questionnaires and semi-structured interviews with 47 academic researchers across selected institutions in Ghana. Quantitative data provided statistical insights into frequency and patterns of AI tool usage, while qualitative responses were thematically an-

alyzed to capture nuanced perceptions and concerns. Findings indicated that AI tools are widely adopted in Ghanaian research and are mostly used for literature reviews, academic writing, idea generation, and citation management. Researchers acknowledge AI's efficiency, usefulness in data analysis, and its role in enhancing productivity. However, concerns emerged around diminished critical thinking, ethical risks, and reduced creativity due to overreliance on AI. Additionally, issues such as academic dishonesty, lack of institutional policies, and insufficient AI literacy were highlighted as key challenges. These insights suggest a strong demand for ethical guidelines, training programs, and clearer institutional regulations to guide responsible AI integration. The implications of these findings are broad. Academic institutions, policy makers, and educators would benefit from this study by using its results to frame ethical AI guidelines. Research professionals and students alike would draw on these insights to reflect on their use of AI and to balance automation with human insight.

The authors suggest that future studies should include a larger and more diverse sample of academic researchers across multiple regions and institutions in Ghana. Also, given that this study treated academic researchers as a relatively homogeneous group, further research should explore discipline-specific differences in AI adoption and perception.

Reference

- Adap, P. (2019). Understanding human intelligence. Academic Press.
- Adjei, S., & Agyeman, I. K. (2024). The integration of Artificial Intelligence tools in academic libraries within Ghana. *Ghana Library Journal*, 29(2), 1-65.
- Al-Zahrani, A., & Alasmari, M. (2024). Ethical integration of AI in higher education: A Middle Eastern Perspective. *Journal of Educational Technology Studies*, 12(1), 45-62.
- Bianchini, S., Borger, V., & Verma, P. (2022). AI tools in academic practice: A review. *Journal of Technological Innovation*, 30(4), 401-419.
- Borger, V., Bianchini, S., & Verma, P. (2023). Artificial intelligence in research workflows. *International Journal of Academic Research*, 11(3), 55-73.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101.
- Celestin, A., Fiase, A., & Nyamekye, D. (n.d.). Digital transformation in Ghanaian higher education: Opportunities And challenges. *Ghana Journal of Innovation and Technology*.
- Chia, S. J., Lau, Y. H., & Ong, R. M. (2025). Chatbots in academia: Friend or foe? *Educational AI Review*, 7(1), 89-102.
- Creswell, J. W., & Clark, V. L. P. (2017). Designing and conducting mixed methods research (3rd ed.). SAGE Publications.
- Dakakni, A., & Safa, S. (2023). Blending empathy with AI in higher education research. *International Journal of Ethics in Technology*, 15(2), 188-202.
- Dergaa, I., & Saad, H. (2023). AI-driven academic research: Opportunities and risks. *Global Education Review*, 9(2), 45-61.
- Gahagan, J., Slipp, N., Chowdhury, R., Kirby, D., Smith, S., McWilliam, S., Carter, N., Anderson, K., Chughtai, S., Robinson, M., & Mueller, R. E. (2023). Reducing barriers to post-secondary education among former youth in care: A scoping review. *International Journal of Educational Research Open*, 5(August), 100303. <https://doi.org/10.1016/j.ijedro.2023.100303>

- Galla, M. T., Johnson, C., & Kim, E. (2025). Classroom collaboration in the AI age: Feedback systems and Student outcomes. *Teaching and Learning with Technology*, 18(1), 33–49.
- Graham, M., & Stough, D. (2025). ChatGPT and public perception: Insights from Reddit and Twitter. *Journal of AI Communication Studies*, 6(1), 50–67.
- Heredia-Carroza, J., & Stoica, R. (2024). Artificial Intelligence in Higher Education: A Literature Review. *Journal Of Public Administration, Finance and Law*, 30, 97–115.
- Kellogg, D., Wang, Y., & Liu, X. (2019). AI writing assistants in higher education: A student perspective. *Journal of Educational Technology Research*, 27(3), 212–229.
- Kim, J. (2025). The AI Co-Scientist Project: A human-centric ethical framework. *Biomedical AI Review*, 3(2), 14–29.
- Li, Y., Zhang, H., & Yoon, S. (2025). AI confidence and human decision-making. *Cognitive Systems Research*, 64, 220–235.
- Liu, H., Tanaka, Y., & Park, J. (2023). AI integration in East Asian higher education. *Journal of Comparative Education and AI*, 12(4), 123–140.
- Maharani, R. (2025). Design ethics in AI collaboration: Preserving humanity. *Ethics and AI Journal*, 9(1), 40–57.
- Mehrotra, A. (2019). Artificial Intelligence in Financial Services - Need to Blend Automation with Human Touch. 2019 International Conference on Automation, Computational and Technology Management, ICACTM 2019, 342–347. <https://doi.org/10.1109/ICACTM.2019.8776741>
- Nills, J. (2012). *Foundations of artificial intelligence*. MIT Press.
- Nyitrai, P. (2025). AI and innovation in criminology: Opportunities and ethical boundaries. *Journal of Digital Social Sciences*, 10(2), 76–89.
- Ocaña-Fernández, Y., Valenzuela-Fernández, L. A., & Garro-Aburto, L. L. (2019). Artificial Intelligence and Its Implications in Higher Education. *Purposes and Representations*, 7(2), 536–552.
- Osakwe, R. N., Lim, S. Y., & Okafor, I. (2023). AI tools and academic integrity in Sub-Saharan Africa. *Africa Journal of Digital Learning*, 3(1), 23–39.

- Pirzado, A., Wang, F., & Tan, C. (2025). Human-like AI and user trust: Implications for research integration. *Journal of Human-AI Interaction*, 11(1), 61–77.
- Ponomarev, S., & Agafonov, I. (2025). Task allocation in human-AI teams: A review. *Computational Sociology Journal*, 6(3), 89–104.
- Qin, Y., Lee, R. T., & Sajda, P. (2025). Perception of an AI Teammate in an Embodied Control Task Affects Team Performance, Reflected in Human Teammates' Behaviors and Physiological Responses. 1–30. <http://arxiv.org/abs/2501.15332>
- Ruwe, D., & Mayweg-Paus, E. (2023). Recalibrating research practice with AI. *European Journal of Educational Technology*, 31(1), 55–74.
- Sarvady, D. (2017). Digital divide and AI access in Africa. *ICT for Development Journal*, 4(3), 80–92.
- Satell, G. (2016). Ethics in artificial intelligence. *Harvard Technology Review*, 91(2), 58–63.
- Sharma, V. (2025). AI in academic research: An African perspective. *International Review of Education and AI*, 13(1), 99–113.
- Siddig, S. (2025). Large language models in education: Alignment and assessment. *Journal of AI in Curriculum Development*, 5(2), 44–62.
- Verma, N., Getenet, D. S., Dann, D. C., & Shaik, T. (2023). Designing an artificial intelligence tool to understand student engagement based on teachers' behaviours and movements in video conferencing. *Computers and Education: Artificial Intelligence*, 5(June), 100187. <https://doi.org/10.1016/j.caeai.2023.100187>
- Xu, Y., Liu, X., Cao, X., Huang, C., Liu, E., Qian, S., Liu, X., Wu, Y., Dong, F., Qiu, C. W., Qiu, J., Hua, K., Su, W., Wu, J., Xu, H., Han, Y., Fu, C., Yin, Z., Liu, M., Zhang, J. (2021). Artificial intelligence: A powerful paradigm for scientific research. *Innovation*, 2(4). <https://doi.org/10.1016/j.xinn.2021.100179>
- Yigitcanlar, T., David, A., Li, W., Fookes, C., Bibri, S. E., & Ye, X. (2024). Unlocking Artificial Intelligence Adoption in Local Governments: Best Practice Lessons from Real-World Implementations. *Smart Cities*, 7(4), 1576–1625. <https://doi.org/10.3390/smartcities7040064>
- Youvan, D. C. (2024). The Role of AI in Revolutionizing Academic Publishing and Knowledge Dissemination. January. <https://doi.org/10.13140/RG.2.2.35215.76962>

Youvan, D. C. (2025). The Future of Knowledge: AI as a Living Publication and the Evolution of Research Dissemination. February. <https://doi.org/10.13140/RG.2.2.26653.22244>

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial Intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education*, 16(1). <https://doi.org/10.1186/s41239-019-0171-0>

Current Trends And Future Prospects Of AI Integration In Mathematics Education: A Systematic Review

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ABSTRACT:

This study reviews trends in artificial intelligence (AI) integration in mathematics education, examining the research designs used, geographical distribution, and key findings from the empirical literature. A systematic review of AI technologies used in mathematics education, including intelligent tutoring systems, chatbots, gamification, and virtual reality, was conducted to assess their impact on learning outcomes. Unlike previous reviews, this study uniquely delineates both technological trends and disparities in AI adoption, with a specific focus on underrepresentation in low- and middle-income countries. The application of AI technologies in mathematics education has improved academic performance and learner engagement in mathematics. Most studies employed quasi-experimental designs. Moreover, most studies originate from high-income countries, with challenges including overreliance on AI and limited teacher technology preparedness. This review was limited to studies written in English from selected databases, excluding grey literature. Most studies from high-income contexts restrict generalisability to low- or middle-income settings. The results highlight the importance of training teachers and strategically investing in AI tools to enhance mathematics teaching and learning outcomes. Successful AI integration should be sensitive to context and driven by equity, fostering personalised, engaging, and critical-thinking-focused learning experiences.

KEYWORDS: Artificial intelligence, mathematics education, learners' achievement, adaptive learning tools, artificial intelligence tools

1.Introduction

Mathematics is a foundational subject necessary for developing problem-solving skills, logical reasoning, and analytical thinking (Geiger et al., 2023). These mental abilities are relevant in daily life and span a wide range of careers. Studying mathematics enhances critical thinking, enabling students to make informed and systematic choices.

Despite its importance, mathematics remains challenging for many students for various reasons, including the following. These challenges include conceptual misunderstandings and cognitive barriers, anxiety, ineffective pedagogical methods, and socio-cultural challenges (Mangarin & Caballes, 2024). Kaya and Keşan (2023) emphasised that these challenges result in students' inability to apply mathematical concepts to real-life situations. Moreover, ineffective teaching methods, particularly traditional lecture-based approaches, fail to foster critical thinking and engagement, and inadequate teacher preparation further impedes learning outcomes (Hissan & Ntow, 2021). Given these persistent challenges in mathematics education, there is a growing need for innovative solutions that enhance conceptual understanding, alleviate anxiety, and improve instructional effectiveness, as traditional teaching methods have often fallen short in encouraging a deep understanding of mathematics.

Artificial intelligence (AI) technologies have emerged as powerful tools for transforming mathematics education. Luckin et al. (2016) and Opesemowo (2024) disclosed that AI technologies transform mathematics teaching through personalised instruction and adaptive feedback. AI systems analyse students' performance and tailor lessons to their needs, fostering understanding beyond memorisation (Hu, 2024). AI-powered virtual tutors provide step-by-step solutions and enhance accessibility for under-resourced students and those with disabilities (Cardona et al., 2023). AI tools were found to reduce math anxiety through gamified learning environments (Wulan et al., 2024). Moreover, AI-powered assessment tools offer continuous evaluation while supporting teachers by automating tasks such as grading (Zawacki-Richter & Jung, 2023). AI analytics help identify at-risk students for intervention (Chassignol et al., 2018). However, AI implementation faces challenges, including issues related to data privacy and the digital divide (Ng et al., 2025). As AI continues to evolve, it will further enhance the field of mathematics education.

While existing systematic reviews have broadly examined AI in education, they lack specific insights. For instance, Gligorea et al. (2023) analysed AI's role in instructional methods through robotics and adaptive learning platforms. Bond et

al. (2024), Fadlelmula and Qadhi (2024), and Zawacki-Richter et al. (2019) also focused on AI in education at various levels. Given the unique traits of mathematics learning and AI's potential, this study systematically synthesises evidence on AI tools in mathematics education, focusing on student learning outcomes.

This systematic review analysed and synthesised the findings on the use of AI in mathematics education. The review will address the following key research questions.

1. How is AI in mathematics education distributed in terms of research design?
2. How is AI used in mathematics education in different countries?
3. What are the key findings of AI in mathematics education?

2. Methodology

2.1 Search strategy

The literature review was conducted utilizing the following databases: Google Scholar, ScienceDirect, Scopus, ERIC, and ProQuest. The search string was created using Boolean operators and structured as follows: ("artificial intelligence") AND ("mathematics education") AND ("learning outcome").

2.2 Selection criteria

The study included articles that focused on the integration of AI tools and their impact on student performance and engagement in mathematics education. Only peer-reviewed articles written in English and published between 2015 and 2025 were included in the review. Conference proceedings, theses, technical papers, reports, and other grey literature were excluded.

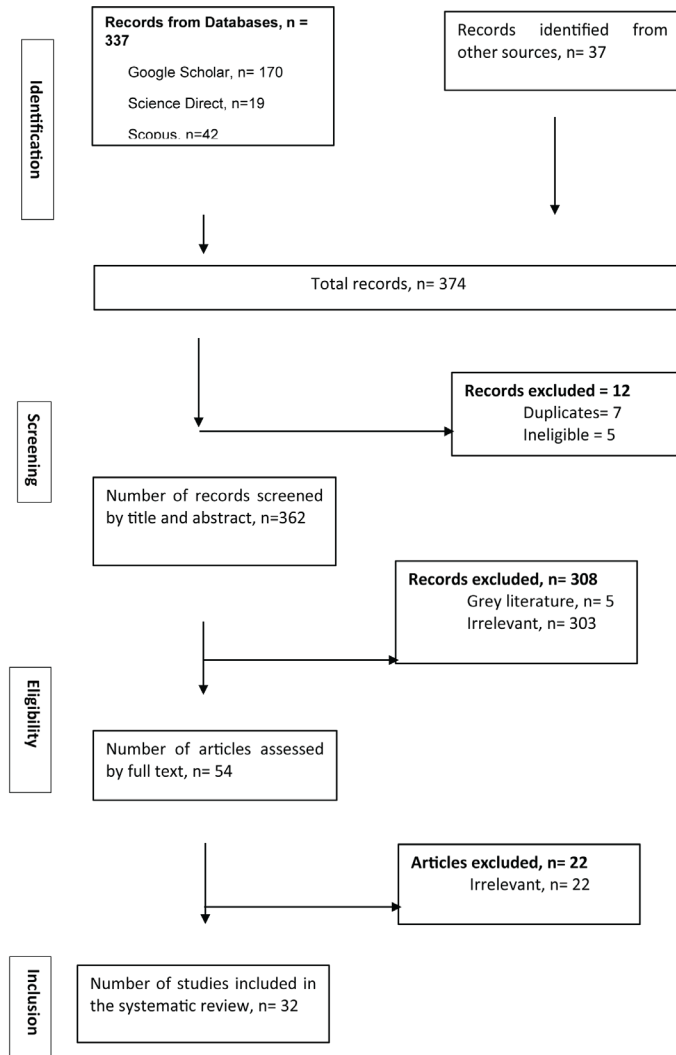


Fig. 1 PRISMA flow chart of selection process (Authors' creation)

3. Findings

3.1 Question 1: How is AI in mathematics education distributed in terms of research designs?

The analysis revealed that the reviewed studies used eleven (11) different research designs: Ethnography, Experimental, multi-scenario, design-based, convergent parallel, descriptive, exploratory, case study, non-experimental, quasi-experimental, and correlational studies. This review showed that 33% (n=11) of the reviewed studies used a quasi-experimental design (Cai et al., 2021; Harper et al., 2021; Jones et al., 2023; Khazanchi et al., 2025; Mills, 2021; Nehring et al., 2023; Ryan, 2018). This was followed by experimental designs with studies (Alvarez, 2024; Cai et al., 2021; Ferro et al., 2021; Shi & Rao, 2022; Tan, 2022). Moreover, correlational designs (Deo et al., 2020; Elsayed, 2023; Mills, 2021; Moreno-Esteva et al., 2018), case studies (Getenet, 2024; Torres-Peña et al., 2024; Wardat et al., 2023), design-based research (Nindiasari et al., 2024; Wardat et al., 2023), and descriptive designs (Azevedo et al., 2024; Jones et al., 2023) were used. Other research designs reviewed included convergent parallel (Xhako et al., 2025), exploratory (Inferio et al., 2024), non-experimental (Moral-Sánchez et al., 2023), multi-scenario (Lopez-Caudana et al., 2020), and ethnography (Harper et al., 2021), which were all used once.

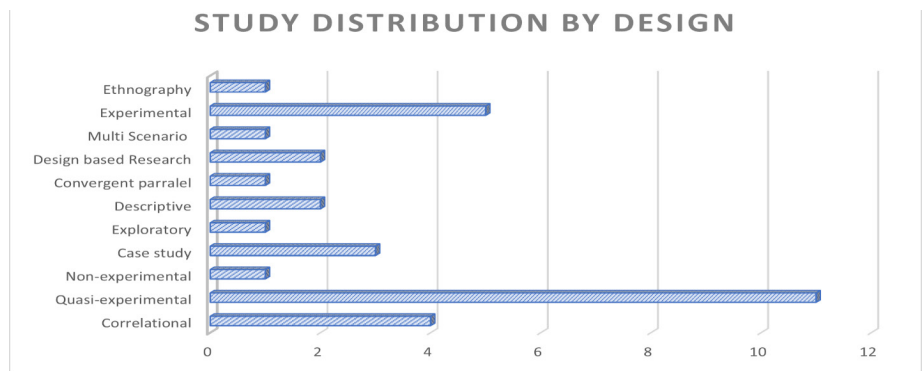


Figure 2. Distribution of reviewed studies by research design

3.2 Question two: How is AI in mathematics education distributed by country?

The second research question focused on the distribution of studies by country of origin. The systematic review revealed that most studies (n = 9) were conducted in North America. The United States contributed seven studies (Cai et al., 2021; Harper et al., 2021; Jones et al., 2023; Khazanchi et al., 2025; Mills, 2021; Nehring et al., 2023; Ryan, 2018), while both Mexico (Lopez-Caudana et al., 2020) and Canada (Bernhardt-Walther & McKeown, 2023) had one study each. Asian countries are showing growing interest in the adoption of AI tools in mathematics education, particularly China (Shi & Rao, 2022; Tan, 2022; Wang, 2014; Zhang, 2023), the Philippines (Inoferio et al., 2024; Alvarez, 2024), Taiwan (Chen et al., 2023), the UAE (Wardat et al., 2023), Saudi Arabia (Elsayed, 2023), and Jordan (Qawaqneh et al., 2023). Meanwhile, studies in Europe are spread across several countries, including Spain (Moral-Sánchez et al., 2023; Romero et al., 2023; Sáez-López et al., 2019), Italy (Ferro et al., 2021), Portugal (Azevedo et al., 2024), Albania (Xhako et al., 2025) and Slovakia (Annuš & Kmeť, 2024). In South America, countries such as Colombia (Torres-Peña et al., 2024) are conducting studies on the use of AI in math education. Australia has also conducted three studies (Deo et al., 2020; Getenet, 2024; Moreno-Esteva et al., 2018) on AI tools in mathematics education.

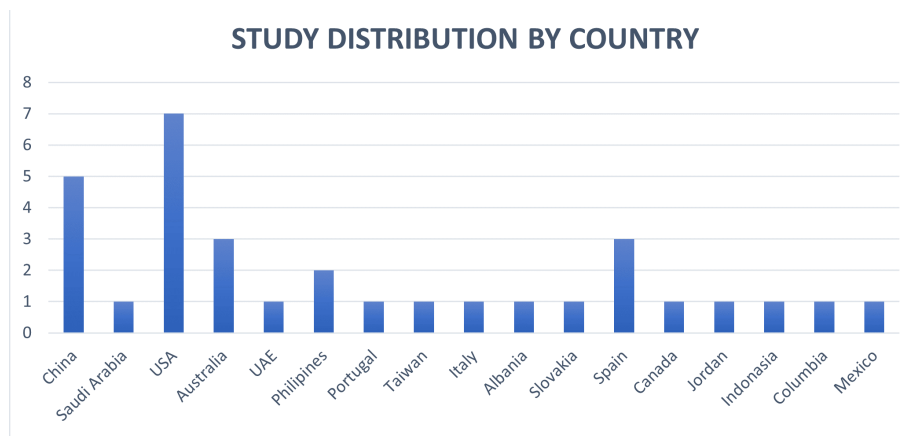


Figure 2. Geographical distribution of studies included in the review

3.3 Question three: What are the key findings of AI in mathematics education studies?

This review has revealed key trends in AI's effectiveness of AI in mathematics education. AI enhances student engagement through virtual laboratories, chatbots, and gamification platforms. Virtual and Augmented reality strengthen conceptual understanding in geometry and calculus (Azevedo et al., 2024; Jones et al., 2023; Qawaqneh et al., 2023; Romero et al., 2023). AI has also been found to enable personalised learning through systems such as Squirrel AI Learning (Wang et al., 2023) and ChatGPT-assisted tutoring, yielding higher learning gains than conventional methods (Elsayed, 2023; Wardat et al., 2023; Xhako et al., 2025).

AI assists educators with assessments through systems such as the Mathematics Learning Strategies Intelligent Assessment System, which provides learning diagnostics for refined instruction (Deo et al., 2020; Ferro et al., 2021; Wang et al., 2022). Tools such as ALEKS, MathGPT, and Flexi 2.0 have improved students' exam scores, with ALEKS showing significant improvements in mathematics performance (Bernhardt-Walther & McKeown, 2023; Mills, 2021; Nehring et al., 2023; Ryan, 2018). Extreme Learning Machines predict student success in engineering mathematics (Deo et al., 2020), whereas ant colony optimisation algorithms enhance mathematics scores (Zhang, 2023). Gamified Educational Robots increase creativity and motivation (Chen et al., 2023), and the NAO robot improves student focus (Lopez-Caudana et al., 2020). MathGPT and Flexi 2.0 provide personalised tutoring (Alvarez, 2024), while Learn with M.E. facilitates differentiated instruction (Annuš & Kmeť, 2024).

While AI has demonstrated benefits, several studies have raised concerns about overreliance and issues related to faculty's preparedness. Concerns have been raised regarding students' blind trust in AI-generated responses from AI tutors. Moreover, it has been established that generative AI tools have difficulty detecting procedural errors in student reasoning (Torres-Peña et al., 2024). Xhako et al. (2025) acknowledged gaps in faculty preparedness for AI-integrated teaching, as only 40% of STEM curricula included AI training.

4. Discussion

Most studies reviewed used quasi-experimental designs, reflecting the challenges of experimental control in educational settings (Giannakos, 2022). Correlational, experimental, and ethnographic designs were rare, with few mixed-methods approaches. This methodological gap limits the understanding of student and teacher experiences with AI technology. Future research should employ diverse methodologies to explore the qualitative aspects of AI in mathematics education.

The United States dominated the research outputs, followed by Asia, Europe, South America, and Oceania. Studies from African countries are notably absent, raising concerns about the representation of African countries in AI educational research. The dominance of high-income countries suggests that AI discussions in mathematics education are shaped by contexts with advanced infrastructure, reflecting unequal access to technology. Future research should prioritise under-represented regions to capture diverse educational realities and promote inclusive AI innovation.

Research question three revealed that AI tools had a positive impact on students' mathematical achievement, motivation, and problem-solving skills, serving as instructional support that enhanced both cognitive and affective outcomes. These systems provide real-time feedback and scaffolded instructions, resulting in greater engagement and understanding among students. However, these improvements may be attributed to novelty effects or increased teacher support during experimental studies (Zhai et al., 2024). Studies caution against overreliance on AI and highlight faculty unpreparedness, underscoring the need for a balanced integration with pedagogical strategies and proper training to ensure effective use.

5. Limitations

The limitations of the current review include the exclusion of non-English studies, focus on recent publications (2015–2025), and a relatively small number of studies. These factors may limit the generalisability of our findings to other populations and settings in the future. Future systematic reviews should expand their scope to include a broader range of sources and methods.

6. Conclusion

This systematic review examined the impact of AI technologies on mathematics achievement and identified key tools and research patterns. The results showed that Intelligent Tutoring Systems and Educational Robots were the most effective AI tools. Most studies used quasi-experimental designs from high-income countries, indicating research disparities. AI technology enhances students' academic performance, motivation, and engagement. However, concerns regarding overreliance on AI and limited faculty preparedness necessitate careful integration into education. Stakeholders should prioritize AI adoption, ethics, faculty training, and digital access. AI technologies can transform mathematics education through thoughtful, evidence-based implementation, ensuring equitable learning for all students.

References

- Alvarez, J.I. (2024). Evaluating the Impact of AI-Powered Tutors MathGPT And Flexi 2.0 In Enhancing Calculus Learning. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, 8(2): 495–508.
- Annuš, N. & Kmeť, T. (2024). Learn with M.E.—Let Us Boost Personalized Learning in K-12 Math Education! *Education Sciences*, 14(7): 773.
- Azevedo, B.F., Pacheco, M.F., Fernandes, F.P. & Pereira, A.I. 2024. Dataset of mathematics learning and assessment of higher education students using the MathE platform. *Data in Brief*, 53: 110236.
- Bernhardt-Walther, K. & McKeown, R.J. (2023). The Impact of ALEKS on Student Learning in First-Year University Mathematics for Economics.
- Bond, M., Khosravi, H., De Laat, M., Bergdahl, N., Negrea, V., Oxley, E., Pham, P., Chong, S.W. & Siemens, G. (2024). A meta systematic review of artificial intelligence in higher education: a call for increased ethics, collaboration, and rigour. *International Journal of Educational Technology in Higher Education*, 21(1): 4.
- Cai, W., Grossman, J., Lin, Z.J., Sheng, H., Wei, J.T.-Z., Williams, J.J. & Goel, S. (2021). Bandit algorithms to personalize educational chatbots. *Machine Learning*, 110(9): 2389–2418.
- Cardona, M.A., Rodríguez, R.J. & Ishmael, K. (2023). Artificial Intelligence and the Future of Teaching and Learning.

- Chassignol, M., Khoroshavin, A., Klimova, A. & Bilyatdinova, A. (2018). Artificial Intelligence trends in education: a narrative overview. *Procedia Computer Science*, 136: 16–24.
- Chen, T.-I., Lin, S.-K. & Chung, H.-C. (2023). Gamified Educational Robots Lead An Increase In Motivation And Creativity In STEM Education. *Journal of Baltic Science Education*, 22(3): 427–438.
- Deo, R.C., Yaseen, Z.M., Al-Ansari, N., Nguyen-Huy, T., Langlands, T.A.M. & Galligan, L. (2020). Modern Artificial Intelligence Model Development for Undergraduate Student Performance Prediction: An Investigation on Engineering Mathematics Courses. *IEEE Access*, 8: 136697–136724.
- Elsayed, S.A.M. (2023). Applications of Artificial Intelligence and Their Relationship to Spatial Thinking and Academic Emotions Towards Mathematics: Perspectives from Educational Supervisors.
- Fadlelmula, F.K. & Qadhi, S.M. (2024). A systematic review of research on artificial intelligence in higher education: Practice, gaps, and future directions in the GCC. *Journal of University Teaching and Learning Practice*, 21(06). <https://open-publishing.org/journals/index.php/jutlp/article/view/806> 24 March 2025.
- Ferro, L.S., Sapio, F., Terracina, A., Temperini, M. & Mecella, M. (2021). Gea2: A Serious Game for Technology-Enhanced Learning in STEM. *IEEE Transactions on Learning Technologies*, 14(6): 723–739.
- Geiger, V., Beswick, K., Fielding, J., Scheiner, T., Kaiser, G., Goos, M. & Fernandez, K. (2023). Investigating critical mathematical thinking when applying mathematics to real-world problems.
- Getenet, S. (2024). Pre-service teachers and ChatGPT in multistrategy problem-solving: Implications for mathematics teaching in primary schools. *International Electronic Journal of Mathematics Education*, 19(1): em0766.
- Giannakos, M. (2022). Common Types of Experimental Designs in CCI and Learning Technology Research. In *Experimental Studies in Learning Technology and Child–Computer Interaction*. SpringerBriefs in Educational Communications and Technology. Cham: Springer International Publishing: 37–45. https://link.springer.com/10.1007/978-3-031-14350-2_5 27 April 2025.
- Gligorea, I., Cioca, M., Oancea, R., Gorski, A.-T., Gorski, H. & Tudorache, P. (2023). Adaptive Learning Using Artificial Intelligence in e-Learning: A Literature Review. *Education Sciences*, 13(12): 1216.

- Harper, F., Stumbo, Z. & Kim, N. (2021). When Robots Invade the Neighborhood: Learning to Teach PreK-5 Mathematics Leveraging Both Technology and Community Knowledge.
- Hissan, Y. & Ntow, F.D. (2021). An Investigation into the Effect of Concept-Based Instruction on Senior High School Students' Geometric Thinking and Achievement in Circle Theorem.
- Hu, J. (2024). The Challenge of Traditional Teaching Approach: A Study on the Path to Improve Classroom Teaching Effectiveness Based on Secondary School Students' Psychology. *Lecture Notes in Education Psychology and Public Media*, 50(1): 213–219.
- Inoferio, H.V., Espartero, M., Asiri, M., Damin, M. & Chavez, J.V. (2024). Coping with math anxiety and lack of confidence through AI-assisted Learning. *Environment and Social Psychology*, 9(5). <https://esp.as-pub.com/index.php/esp/article/view/2228> 29 April 2025.
- Jones, S.R., Long, N.E. & Becnel, J.J. (2023). Design of virtual reality modules for multivariable calculus and an examination of student noticing within them. *Research in Mathematics Education*, 25(2): 219–242.
- Kaya, D. & Keşan, C. (2023). The Connection of Mathematics with Real-Life Situations: Preservice Elementary Mathematics Teachers' Perceptions of Creating and Evaluating Story Problems. *International Online Journal of Primary Education*, 12(2): 118–135.
- Khazanchi, R., Di Mitri, D. & Drachsler, H. (2025). The Effect of AI -Based Systems on Mathematics Achievement in Rural Context: A Quantitative Study. *Journal of Computer Assisted Learning*, 41(1): e13098.
- Lopez-Caudana, E., Ramirez-Montoya, M.S., Martínez-Pérez, S. & Rodríguez-Abitia, G. (2020). Using Robotics to Enhance Active Learning in Mathematics: A Multi-Scenario Study. *Mathematics*, 8(12): 2163.
- Luckin, R., Holmes, W., Griffiths, M. & Forcier, L.B. (2016). An argument for AI in Education.
- Mangarin, R.A. & Caballes, D.O. (2024). Difficulties in Learning Mathematics: A Systematic Review. *International Journal of Research and Scientific Innovation*, XI(IX): 401–405.

Mills, N.J.D. (2021). ALEKS constructs as predictors of high school mathematics achievement for struggling students. *Heliyon*, 7(6): e07345.

Moral-Sánchez, S.N., Ruiz Rey, F.J. & Cebrián-de-la-Serna, M. (2023). Analysis of artificial intelligence chatbots and satisfaction for learning in mathematics education. *IJERI: International Journal of Educational Research and Innovation*, (20): 1–14.

Moreno-Esteva, E.G., White, S.L.J., Wood, J.M. & Black, A.A. (2018). Application of mathematical and machine learning techniques to analyse eye-tracking data enabling better understanding of children's visual-cognitive behaviours. *frontline Learning Research*: 72–84.

Nehring, J., Moyer-Packenham, P. & North, M. (2023). Assessing the effectiveness of an artificial intelligence tutoring system for improving college-level mathematics preparedness in high school students. *Issues In Information Systems*. https://iacis.org/iis/2023/1_iis_2023_128-141.pdf 15 May 2025.

Ng, D.T.K., Chan, E.K.C. & Lo, C.K. (2025). Opportunities, challenges and school strategies for integrating generative AI in education. *Computers and Education: Artificial Intelligence*, 8: 100373.

Nindiasari, H., Pranata, M.F., Sukirwan, S., Sugiman, S., Fathurrohman, M., Ruhimat, A. & Yuhana, Y. (2024). The use of augmented reality to improve students' geometry concept problem-solving skills through the STEAM approach. *Infinity Journal*, 13(1): 119–138.

Opesemowo, O.A.G. (2024). Artificial Intelligence in Mathematics Education: The Pros and Cons. In M. Khosrow-Pour, D.B.A., ed. *Advances in Information Quality and Management*. IGI Global: 1–18. <https://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-6684-7366-5.ch084> 15 January 2025.

Qawaqneh, H., Ahmad, F.B. & Alawamreh, A.R. (2023). The Impact of Artificial Intelligence-Based Virtual Laboratories on Developing Students' Motivation Towards Learning Mathematics. *International Journal of Emerging Technologies in Learning (IJET)*, 18(14): 105–121.

Romero, I., Rodríguez-Martínez, J.A. & Rodríguez, J.L. (2023). Optimizing the surface of orthohedra with virtual reality in primary school. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(9): em2325.

Ryan, G. (2018). Introduction to positivism, interpretivism and critical theory. *Nurse Researcher*, 25(4): 14–20.

Sáez-López, J.-M., Sevillano-García, M.-L. & Vazquez-Cano, E. (2019). The effect of programming on primary school students' mathematical and scientific understanding: educational use of mBot. *Educational Technology Research and Development*, 67(6): 1405–1425.

Shi, Y. & Rao, L. (2022). Construction of STEAM Graded Teaching System Using Backpropagation Neural Network Model under Ability Orientation R. Ali, ed. *Scientific Programming*, 2022: 1–9.

Tan, J. (2022). Information Analysis of Advanced Mathematics Education-Adaptive Algorithm Based on Big Data N. Jan, ed. *Mathematical Problems in Engineering*, 2022: 1–9.

Torres-Peña, R.C., Peña-González, D., Chacuto-López, E., Ariza, E.A. & Vergara, D. (2024). Updating Calculus Teaching with AI: A Classroom Experience. *Education Sciences*, 14(9): 1019.

Wang, G., Chen, X., Zhang, D., Kang, Y., Wang, F. & Su, M. (2022). Development and Application of an Intelligent Assessment System for Mathematics Learning Strategy among High School Students—Take Jianzha County as an Example. *Sustainability*, 14(19): 12265.

Wang, T.-H. (2014). Developing an assessment-centered e-Learning system for improving student learning effectiveness. *Computers & Education*, 73: 189–203.

Wardat, Y., Tashtoush, M.A., AlAli, R. & Jarrah, A.M. (2023). ChatGPT: A revolutionary tool for teaching and learning mathematics. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(7): em2286.

Wulan, D.R., Nainggolan, D.M., Hidayat, Y., Rohman, T. & Fiyul, A.Y. (2024). Exploring the Benefits and Challenges of Gamification in Enhancing Student Learning Outcomes. *Global International Journal of Innovative Research*, 2(7): 1657–1674.

Xhako, D., Hoxhaj, S., Hyka, N. & Spahiu, E. (2025). Integrating AI applications into university STEM study programs using Python. *International Journal of Innovative Research and Scientific Studies*, 8(1): 2374–2384.

Zawacki-Richter, O. & Jung, I. eds. (2023). Handbook of Open, Distance and Digital Education. Singapore: Springer Nature Singapore. <https://link.springer.com/10.1007/978-981-19-2080-6> 27 September 2024.

Zawacki-Richter, O., Marín, V.I., Bond, M. & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education*, 16(1): 39.

Zhai, C., Wibowo, S. & Li, L.D. (2024). The effects of over-reliance on AI dialogue systems on students' cognitive abilities: a systematic review. *Smart Learning Environments*, 11(1): 28.

Zhang, Q. (2023). Investigating the Effects of Gamification and Ludicization on Learning Achievement and Motivation: An Empirical Study Employing Kahoot! and Habitica. *International Journal of Technology-Enhanced Education*, 2(1): 1–19.

Are They AI-Literate? Exploring The Impact Of Generative AI Literacy On Academic Performance Among Ghanaian University Students

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ABSTRACT:

The rapid adoption of Generative Artificial Intelligence (GenAI) in higher education presents both opportunities and challenges, particularly in under-resourced settings where student preparedness remains uncertain. Drawing on Connectivism learning theory, this study investigates whether perceived GenAI literacy predicts academic performance among Ghanaian university students, a relationship that has not been thoroughly explored in the Global South. A cross-sectional survey conducted in July 2024 collected data from 193 students across various disciplines. Measures included the AI Literacy Scale and the Academic Performance Scale. Analyses using Partial Least Squares Structural Equation Modelling (PLS-SEM) in SmartPLS 4 revealed that students reported moderate levels of GenAI literacy ($M = 59.10$, $SD = 8.72$) and academic performance ($M = 16.33$, $SD = 2.84$). The results indicated a significant positive relationship ($\beta = 0.477$, $p < 0.001$), explaining 21.3% of the variance in academic performance ($R^2 = 0.213$) with a medium to high effect size ($f^2 = 0.268$). Age and gender had no significant effect, highlighting GenAI literacy as a key cognitive factor in technology-mediated learning. These findings support the idea that students' ability to engage meaningfully with intelligent digital tools can enhance academic success. To optimise learning outcomes, institutions should incorporate GenAI competencies, such as prompt design, ethical assessment, and critical evaluation of AI-generated content, into their curricula. Although reliance on self-reported data and a single-institution sample may limit generalisability, the study offers timely insights for educators and policymakers seeking to promote responsible and inclusive GenAI adoption in higher education.

KEYWORDS: Generative Artificial Intelligence, AI literacy, Academic performance, Higher education, Connectivism, Ghana

1. Introduction

The rapid advancement of artificial intelligence technologies is transforming various sectors of national development, and education is no exception. Among these cutting-edge technologies, the Generative Artificial Intelligence (GenAI) tool has emerged at the forefront of educational technology discussions. GenAI refers to a class of technologies that are capable of producing content and imitating human-like intelligence (Belkina et al., 2025; Bozkurt, 2024; Essel, Vlachopoulos, Tachie-Menson, et al., 2025; Kalota, 2024; O'Dea et al., 2024). These technologies offer new tools that can enhance teaching and learning, academic achievement and the ability of learners to critically engage with and ethically use GenAI—referred to as GenAI literacy, has emerged as a critical component of digital competence (Essel, Vlachopoulos, Tachie-Menson, et al., 2025; Ng et al., 2021b).

Due to the user-friendly interface and the fact that users are not required to possess specialised AI knowledge and coding skills, GenAI tools quickly gain traction among university students globally (Bender, 2024; O'Dea et al., 2024). The widespread use by students highlighted ethical issues that erode critical engagement and overdependence on GenAI-generated outputs (O'Dea, 2024; Tili et al., 2025). Therefore, universities must promote transparency in the AI process and promote GenAI literacy among students to allow informed and ethical use (O'Dea et al., 2024; Wang et al., 2023).

While earlier studies in the pre-GenAI era concentrated on AI literacy (Long & Magerko, 2020; Ng et al., 2021a, 2021b), varying definitions have emerged. For instance, Kandlhofer et al. (2016) describe AI literacy as technological knowledge underpinning AI systems, while Long and Magerko (2020) emphasise user competencies to understand, apply, and evaluate AI in both professional and daily contexts. Ng et al. (2021b) further outline four competencies: understanding, application, evaluation, creation, and ethical awareness. According to Wang et al. (2023), AI literacy research serves three main purposes: to understand human-AI interaction, assess user competencies, and guide curriculum development.

AI literacy has been widely acknowledged as essential for all users, not just technical experts. (Laupichler et al., 2022). However, a conceptual distinction must be made between AI and GenAI literacy. Traditional AI literacy is rooted in technical competencies, typically associated with STEM fields, such as machine learning and data science. In contrast, GenAI literacy places greater emphasis on ethical, social, and responsible usage of (say ChatGPT, DALL-E, Midjourney), tailored for non-STEM users. GenAI tools, designed to be accessible and intuitive, allow users to generate multimodal content with minimal technical knowledge. Despite

the growing ubiquity of GenAI, research on GenAI literacy remains underexplored globally compared to the broader discussion of AI literacy.

Additionally, the introduction of GenAI tools into the educational context has transformed the way learners access information, generate content, and complete academic tasks. The actual integration of AI in university lecture halls has been left primarily to the discretion of the faculty.(Adarkwah, 2024; Essel et al., 2024). Recent studies highlighted that Ghanaian higher education students are familiar with ChatGPT as a learning tool, indicating a growing awareness and adoption of GenAI applications in academic settings. (Baidoo-Anu et al., 2024; Baidoo-Anu & Owusu Ansah, 2023; Bonsu & Baffour-Koduah, 2023; Salifu et al., 2024). However, GenAI literacy encompasses more than tool usage; it includes knowledge of GenAI capabilities and limitations, prompt engineering, ethical and responsible use, critical evaluation of AI outputs and integration into academic tasks. Without this understanding, educational institutions may face challenges in aligning their curricula with the demands of an AI-enhanced learning environment.

While existing literature has explored the impact of specific generative AI tools like ChatGPT on student academic performance through experimental (Essel et al., 2024) and adoption-focused approaches (Baidoo-Anu, 2024; Bonsu & Baffour-Koduah; Salifu et al., 2024), there is a dearth of literature on how GenAI literacy as a broader competence influences academic outcomes of undergraduates in Ghana. This study addresses this gap by operationalising GenAI literacy and exploring its predictive role on academic achievement among university students in Ghana. The research objectives specifically addressed in this study are as follows:

1. To examine the perceived GenAI literacy levels and academic performance of university students.
2. To examine the relationship between GenAI literacy and Academic performance.

2. Theoretical Framework and Hypothesis Formulation

This study is grounded in Connectivist learning theory. (Siemens, 2018). This theory posits that learning in the digital age occurs across distributed networks, thus, both human and non-human. Knowledge is no longer limited to individual cognition of formal instructions (Corbett & Spinello, 2020; Carto et al., 2022; Liu & Li, 2022). Students acquire, create, and apply knowledge, including knowledge of AI systems (Al-Hail et al., 2024). In the context of this study, GenAI literacy reflects a student's ability to effectively navigate and utilise GenAI tools (such as ChatGPT, DALL-E, Bard) to access, evaluate and synthesises information across digital platforms. This aligns with Siemens's assertion that the "capacity to know is more critical than what is currently known" (Siemens, 2005, p. 5).

2.1 AI and GenAI literacy

The rapid emergence of generative AI has transformed the landscape of teaching and learning. Both educators and learners alike must develop a deep, critical know-how of these disruptive technologies (Bozkurt, 2024; Chen et al., 2024). Generative AI technologies have gained more popularity with the release of ChatGPT by OpenAI in November 2022 and have since formed a part of daily lives (Blancia et al., 2024; Wiredu, 2023). GenAI literacy emerges as a subset of AI literacy with a prime focus on how learners use and evaluate GenAI outputs ethically. (Annapureddy et al., 2025; Bozkurt, 2024; O'Dea et al., 2024). GenAI literacy involves basic skills in prompt creation, results evaluation and understanding ethical implications (Bozkurt, 2024; Jin et al., 2024; Zhao et al., 2022).

Generative AI, such as ChatGPT, is being widely used in education. Božić & Poo-la (2023) showed that ChatGPT helps students improve language acquisition through chatbots and online tutors. At Harvard, Hirabayashi et al. (2024) found that about 90% of students use GenAI, which is changing how they study, select courses, and consider future job opportunities. However, many students are also worried that AI could reduces job opportunities and increase inequality. Deschenes & McMahon (2024) found that 65% of Harvard students use or plan to use GenAI for tasks like summarising and proofreading. Still, 80% are concerned about the trustworthiness and ethics of these tools. Sharples (2023) suggested that GenAI could support teamwork in schools and act as a team partner. Ng et al. (2024) also found that a GenAI chatbot called SRLbot helps secondary school students learn science better than the older AI system by boosting their motivation and interest.

With AI not just a frontier technology, studies have investigated the proficiency levels of university students, prospective teachers, and nurses. This is in line with one of the basic tenets of studying AI literacy (Wang et al., 2023). Bozkurt (2024) opines that different users of GenAI will have varying proficiency levels, ranging from basic to advanced, which will be sufficient in all cases. In a study by Özden et al. (2025) pre-service teachers were reported to have demonstrated high AI literacy. Obenza et al. (2024), Shen and Cui, (2024) and Wang et al. (2023) reported above average perceived proficiency levels of GenAI technologies. This finding suggests that students possess a comprehensive understanding and practical application of AI tools. In contrast, Chenqi et al. (2023) and Sari et al. (2025) reported a low GenAI literacy competency level of prospective teachers in China and undergraduates in Indonesia, respectively.

Several studies in Ghana have explored the educational use and impact of generative AI tools like ChatGPT and virtual assistants. (Essel et al., 2022;2025) develops and tests AI-powered teaching assistants – KNUSTbot and KNUST-Vbot, operationalised with zero coding on WhatsApp and Voicebots, respectively, showing improved academic performance among students. A study by Essel et al. (2024) further revealed that students who used ChatGPT for class assignments significantly enhanced their critical, creative, and reflective thinking skills compared to those who used traditional methods. Bonsu and Baffour-Koduah (2023) reported positive attitudes among students and a strong intention to integrate ChatGPT into learning, while Baidoo-Anu and Owusu Ansah (2023) highlighted the benefits of ChatGPT, such as automated tutoring and grading, but also raised concerns about privacy and the lack of interpersonal interactions. Salifu et al. (2024), using the UTAUT2 model, found that factors such as trust, social influence, and especially hedonic motivation significantly shaped students' behavioural intention and actual use of Chat GPT in higher education.

2.2 Academic Performance

The primary focus of any educational innovation is to enhance student performance in both academic and non-academic tasks. In general, the Academic performance of the learner is reflected by assessing the results achieved by the learner in various subjects. Students' academic performance may likely determine their future goals and objectives ((Commey-Mintah et al., 2023; Tetteh & Agyei, 2022). The degree of students' academic performance is measured based on the laid down benchmark of the school, but it is measured chiefly using students' Grade Point Average (GPA) (Mehrvarz et al., 2021; Singh et al., 2024) In this study, a self-reporting scale will be used to measure the academic performance of university students.

2.3 GenAI Literacy and Academic Performance

The academic performance of students can be improved through the integration of digital media with learning. As higher educational institutions integrate GenAI technologies into their curricula, GenAI literacy has become a pervasive skill necessary to make this transformation possible. (Kamau, 2025; Ng et al., 2023). Liang et al. (2023) opines that GenAI literacy is an essential driver in global education. It is identified as a potential predictor of academic performance in an AI-mediated learning environment (Chiu et al., 2024). Several studies have looked at the relationship between AI literacy and academic performance. Singh et al. (2024) report that AI literacy significantly impacts the academic performance of Gen Z students in India. Thus, AI literacy is essential in improving their learning experiences and fosters critical and innovative thinking among Gen Z students. Xiao et al. (2024) undertook a study to understand the role of AI literacy in enhancing student achievement in online learning environments. Their analysis shows that AI literacy is not only a direct determinant of academic well-being and educational success but also mediates the effect of academic well-being on educational success. According to Youssef et al. (2024), using ChatGPT positively and statistically contributes to Emirati students' academic achievements. Al-Mamary et al. (2024) and Elbaz et al. (2024) discovered that implementing ChatGPT in e-learning positively influences the academic performance of university students. Kamau (2025) reported a positive significant relationship between generative artificial intelligence and learning outcome among undergraduate students in Kenya ($\beta = 0.387$, $t = 7.353$, $p < 0.000$).

While some studies indicated a significant correlation between academic performance and AI literacy, others reported contrasting findings. Asio (2024) identified a weak positive correlation between academic performance and AI literacy. Bancoro (2024) reported no significant relationship between the use of AI and academic performance. Furthermore, the research conducted by Mansoor et al. (2024) indicates a negative correlation between academic performance and AI literacy. Students who demonstrate inferior academic performance may be inclined to depend more heavily on AI tools to accomplish their academic assignments. Based on the above findings, the researcher posits;

H1: GenAI literacy positively and significantly impacts the academic performance of university students

3. Research Methodology

3.1 Research Model

This study aimed to explore the relationship between GenAI literacy and Academic performance among university students as given in the model explaining the hypothesised connections among the research constructs (Figure 1)



Figure 1 Research Model

3.2 Research Design and Method

This research employed a quantitative research design, utilising a survey method to conduct the investigation. Data was collected from the university students using a structured questionnaire. The structured questionnaire is made up of 16 statements associated with GenAI literacy (12 items) and academic performance (4 items). All the statements were measured on a 7-point Likert-type scale ranging from strongly disagree to strongly agree. Demographic data, including age, gender, and usage of GenAI tools, were also collected.

3.3 Measurement instrument

3.3.1 GenAI Literacy Scale

The GenAI literacy proficiency of the university students was assessed using the 12 items AILS developed by Wang et al. (2023). The 7-point Likert-type scale has four sub-dimensions: Awareness, Usage, Evaluation, and Ethics. The scale items are carefully designed to measure participants' levels of GenAI literacy, thereby providing a comprehensive understanding of students' GenAI literacy. A maximum score of 84 and a minimum score of 12 can be obtained. The higher the score, the higher the perceived GenAI literacy, and vice versa. The internal consistency of the overall scale is 0.85. In the context of this study, the internal consistency was 0.853.

3.3.2 Academic Performance Scale

Scholarly studies measure academic performance using various methods, including self-reported GPA or CWA (Essel et al., 2021; Katalbas et al., 2023), and students' perceived ability to complete an academic task (Han & Yi, 2019; Mehrvarz et al., 2021). This study adopted a four-item academic performance scale from Merhvaz et al. (2021), who had reported a reliability of 0.86. The student rated each item on a 7-point Likert scale. The internal consistency of the scale in this study was 0.824.

3.4 Population and Sampling

The study population consisted of undergraduate students from Kwame Nkrumah University of Science and Technology (KNUST), a public university in Ghana that offers a diverse range of academic programmes. The participants were selected through a convenience sampling method. This approach was selected due to practical considerations in reaching the students. G*Power, a priori statistical tool, suggest that a minimum of 89 valid responses is necessary to achieve 95% statistical power for conducting a Partial Least Squares- Structural Equation Modelling (PLS-SEM) analysis (Faul et al., 2007, 2009) 193 valid responses was used for the analysis in this study, which is above the minimum sample size. Students were included in the study if they met the following criteria: being a KNUST student, being able to read and understand English, having access to the internet, and volunteering for the study. The exclusion criteria are that the participant can leave the study at any time or by not consenting to partake in the study. Data was collected between 1st July and 31st July, 2024. Age and gender were included in the model as control variables to account for potential demographic influence on Academic performance. Both were modelled as single-item constructs with direct paths to the outcome variable.

3.5 Data Collection and Analysis

The scales were created in a survey format using Google Forms. The survey link was sent to the teaching assistant to be shared with students via their WhatsApp groups, and QR codes were printed and posted at vantage points on campus. The participant was directed to the Google Forms survey by clicking on the link. Participants who consented to the survey were directed to the main survey; for those who did not consent, the survey was terminated. The researchers received a total of 262 survey responses from the students. The responses were carefully screened for data accuracy before data analysis.

This study employed the PLS-SEM to analyse the relationship between GenAI literacy and Academic performance. Since PLS-SEM is a non-parametric technique,

it does not require the assumption of multivariate normality to be met. The dataset was examined for multivariate normality through the WebPower analysis tool. (Cain et al., 2017). Mardia's multivariate skewness and Kurtosis measures were found to be significant, indicating non-normality and therefore, covariance-based SEM (CB-SEM) would not be appropriate for the analysis. The reliability and validity of the measures were analysed through measurement modelling, and the SEM was performed to measure the relationship between the variables.

4. Findings and Discussion

4.1 Demographic Characteristics

The study involved 193 participants with a mean age of 22.07 years (SD = 2.87). Of these, 117 were identified as male and 76 as female. When asked about their use of generative AI tools for generating ideas in assignments or projects, the top three tools reported were ChatGPT (169 users, 87.6%), Grammarly AI (74 users, 38.8%), and Microsoft Copilot (50 users, 25.9%). The result indicated that ChatGPT is the dominant tool among students, with many also leveraging additional tools to support their academic pursuit (see Table 1).

Table 1 Sample Demographics

Variables		N	Mean	SD	%
Age		193	22.10	2.87	
Gender	Male	117			60.6
	Female	76			39.4
GenAI used	ChatGPT	169			87.6
	Grammarly AI	74			38.8
	Microsoft Copilot	50			25.9

(Source: The Authors)

4.2 Descriptive Analysis

The level of GenAI literacy and academic performance was assessed through descriptive analysis of the surveyed sample (Table 2). All constructs were measured on a 7-point Likert-type scale. The total mean scores are AIL (M = 59.098, SD = 6.718) and AP (M = 16.326, SD = 2.836), respectively. The average GenAI literacy score of 59.098 indicates a good understanding and practical application of GenAI tools among university students. There is a positive moderate correlation between AIL and AP ($r = .382, p < .001$)

Table 2 Descriptive Statistic

Variables	N	Minimum	Maximum	Mean	SD
AIL	193	1	7	59.098	8.718
AP	193	1	7	16.326	2.836

Correlation among variables

AIL and AP	0.382***

*** $p < 0.001$

4.3 Common Method Bias

Before estimating the model, the dataset was checked for common method bias (CMB). CMB may exist in research where variables are latent and measured through instruments on a similar type of scale. This type of bias can occur for various reasons, such as the effect of general instructions at the beginning of the instrument, which influences different people to give responses in a similar direction, reflecting social desirability and leading to shared common variance among the items. (Kock, 2015; Memon et al., 2023). This study employed a 7-point Likert scale to measure the variables, full collinearity assessment was conducted to rule out the presence of CMB in the data. Using the full approach, inner VIF values of the constructs are tested against a random endogenous variable, and any value coming above 3.3 indicates a problem of CMB (Kock & Lynn, 2012). In this study, none of the inner VIFs for the variables exceeded 3.3, which implies that the problem of CMB does not exist (Kock, 2015)

4.4 The Measurement Model Assessment

The measurement model assessment entails the examination of the indicator reliability, the internal consistency reliability, convergent validity and the discriminant validity of the construct. Validity refers to how the scale measures the intended construct accurately (Hair et al., 2019). Construct validity comprises both convergent and discriminant validity, which are evaluated and established through benchmark values (Sarstedt et al., 2021). Convergent validity, which is a key component of construct validity, assesses the degree to which several items of the same construct are in harmony (Henseler et al., 2015). Convergent validity in PLS-SEM is mostly evaluated using two major criteria: factor loading and the average variance extracted (AVE). The acceptable benchmark in current literature for these criteria is factor loading > 0.70 and AVE > 0.50 (Henseler et al., 2015). Multiple iterations of the PLS-SEM were run to achieve satisfactory factor loadings. This led to the removal of several items due to factor loadings below the 0.707 threshold if they do not affect the construct validity (i.e., CR and AVE). We eliminated six items (AIL 11, AIL 5, AIL 2, AIL 12, AIL 10, AIL 1) from the construct measuring GenAI literacy. Despite being below the threshold, we retained item AIL 3 because the CR is greater than 0.70 and the AVE is greater than 0.50 (Hair et al., 2019).

We expect the internal consistency reliability to account for approximately 70% of the construct, and we should also take a composite reliability of more than 0.70 into consideration (Ringle et al., 2020; Taber, 2018). The Table xx demonstrates that the composite reliabilities for the GenAI literacy factor (0.853) and Academic Performance (0.824) are all higher than the benchmark value of 0.70. Convergent validity checks how all the items add up and explains about half of the construct. This was measured through the average variance extracted (AVE); the acceptable value must be more than 0.50 (Hair et al., 2019). Table 3 shows that all AVEs for the respective constructs are well above 0.50.

Table 3 Reliability and Validity

Construct	Factor loadings	Cronbach Alpha	rho_A	rho_C	AVE
AIL		0.853	0.871	0.891	0.578
AIL3	0.619				
AIL4	0.790				
AIL6	0.755				
AIL7	0.798				
AIL8	0.761				
AIL9	0.823				
AP		0.284	0.828	0.883	0.654
AP1	0.809				
AP2	0.781				
AP3	0.829				
AP4	0.815				

(Source: The Authors)

4.5 Discriminant validity

The discriminant validity of a construct in the structural model refers to how distinct it is from other constructs (Hair et al., 2018; Lim, 2024). Consequently, there should be no overlap of questions among constructs. We use the HTMT to measure the discriminant validity, with a benchmark requiring the HTMT to not exceed 0.90 (Henseler et al., 2015; Kline, 2023). Table 4 demonstrates that each construct has an HTMT of less than 0.90, thereby satisfying the criterion for confirming the model's discriminant validity.

Table 4 HTMT Criterion for Discriminant Validity

	AIL	AP
AIL		
AP	0.526	

4.6 The structural model Assessment

As the initial step in structural model analysis, the inner VIF values were examined to rule out the tendency of multicollinearity. All inner VIF values were found to be below 5, thus ruling out the presence of any serious multicollinearity issues among the model's variables (Hair et al., 2019). The model was then assessed for explanatory power using the coefficient of determination (R^2) and a bootstrapping procedure to evaluate the structural relationships. The effect size of the predictor variable was also calculated. The model fit assessment in PLS-SEM was done through the recommended Standardised Root Mean Square Residual (SRMR) value (Hair et al., 2022; Henseler et al., 2015). The SMMR value below 0.08 indicates a satisfactory model fit (Hu & Bentler, 1999)

4.7 Explanatory Power (R^2)

The R^2 , called the in-sample predictive power, measures the model's explanatory power. For each path between constructs, the ideal R^2 value should be at least 0.1 or higher (Falk & Miller, 1992). Understanding R^2 values within the study context is crucial. Values of 0.75, 0.50, and 0.25 are considered substantial, moderate, and weak, respectively (Hair et al., 2011; Hair et al., 2018; Lim, 2024). Table 5 above demonstrates that the R^2 for academic performance is 0.213, signifying that Gen AI competency accounts for 21.3 % of the variation in academic performance.

4.8 Effect size (f²)

The effect size (f²) checks how important each independent variable is in explaining the dependent variable. It is classified as large, medium, or small when it exceeds or equals 0.35, 0.15, and 0.02, respectively(Cohen, 1992). Gen AI literacy (f² = 0.268) has medium to strong effects in explaining academic performance (Table 5)

Table 5 Explanatory Power & Model Fit

Explanatory Power: R-squared		
	R Square	R Suare Adjusted
AP	0.213	0.201
Effect size: f-square		
	AIL	AP
AIL		0.268
Model fit		
SRMR	0.068	

(Source: The Authors)

The inner model presents the hypothesised model paths within the research framework for empirical testing. The Hypothesis was tested by running the consistent PLS algorithm in SmartPLS 4 software. Bootstrapping was run using 10,00 subsamples to test the significance of the coefficients. The structural model for the result is presented in Table 6, and Figure 2 shows the model estimation results. The relationship between AIL and AP is significant except for the path coefficients of the control variables.

Table 6 Structural Model Results

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (O/STDEV)	P values	Inference
AILS-> AP	0.478	0.489	0.080	5.948	0.000	Accepted
Control variables						
Age-> AP	-0.085	-0.086	0.082	1.043	0.297	Rejected
Gender-> AP	0.020	0.023	0.130	0.156	0.876	

(Source: The Authors)

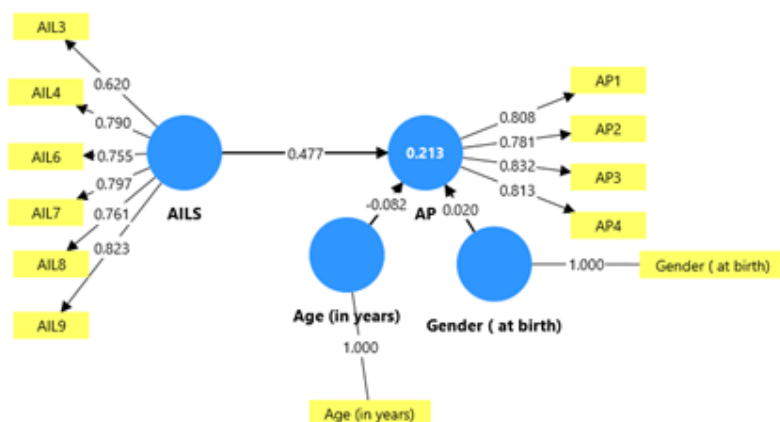


Figure 2 Model Estimation Results

(Source: The Authors)

5.0 Discussion

This study, grounded in Connectivism learning theory, employs structural equation modelling to investigate the relationship between perceived GenAI literacy and academic performance of university students, specifically in the context of a resource-constrained GenAI-mediated learning environment in Ghana.

The students rated their perceived GenAI literacy levels as moderate, due to their proficiency in using the GenAI tool for academic tasks at its elementary stage, and they will need more training to gain a more comprehensive understanding of its application and usefulness. Considering the pace with which GenAI technologies are supercharging all aspects of life, it is therefore desirable that the perceived levels of university students are not low. This finding aligns with similar studies by Cegiz and Peker (2025), Kahraman et al. (2025), and Cayak (2024), which reported a moderate proficiency level of AI literacy. The moderate perceived proficiency levels of university students differ from those reported by Ozden et al. (2025) and Obenza (2024), who found a high AI literacy level, and Chenqi et al. (2023) and Sari et al. (2025), who reported a low AI literacy level in their studies.

This study highlights a significant positive relationship between GenAI literacy and the academic performance of university students. GenAI literacy accounts for 21.3 % of variance in student academic performance, with a medium to high effect size ($f^2 = 0.268$). Although modest, this level of explanatory power is considerably acceptable within social and educational research, where numerous factors affect learning outcomes. This underscores the importance of GenAI literacy in fostering meaningful learning experiences. Thus, students with high AI literacy are able to leverage GenAI tools in streamlining their academic tasks. These findings resonate with prior studies (Singh et al., 2024; Kamau, 2025; Xiao et al., 2024), highlighting the positive and significant relationship between GenAI literacy and academic performance. University students are highly receptive to technological tools for improving their learning outcomes and a broader educational experience, due to the digitalisation drive and technology-mediated learning environment. In addition, the proficiency of students in GenAI literacy equips them with the requisite skills to explore the AI-driven ecosystem seamlessly (Essel et al., 2024; Baidoo-Anu & Owusu Ansah, 2023). This consequently influences the student's academic achievement and enhances their self-efficacy in executing academic tasks. This finding, however, is contrary to those of Abbas et al. (2019) and Asio and Gadia (2024), which report a weak but positive relationship between AIL and academic performance. Moreso with Mansoor et al. (2024) reporting a negative correlation

between AIL and academic performance. Contrary to the findings of this study, Bancoro (2024) reported no significant relationship between AI literacy and academic performance. This highlights the existence of several dynamics that may influence academic achievement beyond AI literacy.

The non-significant effect of age and gender are consistent with studies suggesting that demographics variables may play a limited role in predicting proximal cognitive factor like GenAI literacy (Sari et al.,2025; Mansoor et al.,2024; Ozden et al., 2025; Shen & Cui,2025) This reinforces the central role of GenAI literacy a key predictor of academic performance.

6.0 Conclusion and Further Research

The study, grounded in connectivism learning theory, found a significant positive relationship between perceived GenAI literacy and academic performance among university students in a resource-constrained Ghanaian context. GenAI literacy accounted for 21.3% of the variance in academic performance, with a medium-to-high effect size ($f^2 = 0.268$), highlighting its role as a key cognitive factor in technology-mediated learning environments. Moreover, demographic variables such as age and gender showed no significant effect, reinforcing the centrality of GenAI literacy as a predictor of Academic performance. In alignment with the principle of connectivism, the finding suggests that students' ability to navigate intelligent digital networks meaningfully enhances learning efficacy.

This study relied on self-reported data and employed a cross-sectional design, which may have affected the accuracy and causality of the findings. Additionally, the focus on a single university in Ghana limits the generalisability of the results. We did not analyse academic levels because the sample was uneven, and it was not part of the study's original aim.

Future research should investigate how the structure of GenAI training influences learning outcomes over time, employing a longitudinal or experimental design. Expanding to diverse disciplines, academic levels, and contexts would ensure generalisability. At the same time, attention to instructional and policy-level readiness could inform more equitable and effective integration of GenAI in the higher education system.

7. Ethical considerations

This study adhered to the Helsinki Declaration and received approval from the ethics committee of the Department of Educational Innovation in Science and Technology, KNUST (EIST-EC-0107-2024s, approved July 1, 2024). Data collection began after the approval. Participants first read a research preamble and provided informed consent, indicating voluntary participation through survey submission.

References

- Adam, I. O., Alhassan, M. D., & Diack, A. (2024). Exploring Students Foundational Skills in Integrating Generative AI in Ghanaian Higher Education: A Constructive Learning in Ghanaian Higher Education. Thirtieth Americas Conference on Information Systems, August, 1–10. <https://aisel.aisnet.org/amcis2024>
- Adarkwah, M. A. (2024). GenAI-Infused Adult Learning in the Digital Era: A Conceptual Framework for Higher Education. *Adult Learning*, 0(0), 1–13. <https://doi.org/10.1177/10451595241271161>
- Al-Mamary, Y. H., Alfalah, A. A., Shamsuddin, A., & Abubakar, A. A. (2024). Artificial intelligence powering education: ChatGPT's impact on students' academic performance through the lens of technology-to-performance chain theory. *Journal of Applied Research in Higher Education*. <https://doi.org/10.1108/JARHE-04-2024-0179> <https://doi.org/10.1108/JARHE-04-2024-0179>
- Annapureddy, R., Fornaroli, A., & Gatica-Perez, D. (2025). Generative AI Literacy: Twelve Defining Competencies. *Digital Government: Research and Practice*, 6(1), 1–21. <https://doi.org/10.1145/3685680>
- Asio, J. M. R. (2024). Artificial Intelligence (AI) Literacy and Academic Performance of Tertiary Level Students: A Preliminary Analysis. *Social Sciences, Humanities and Education Journal (SHE Journal)*, 5(2), 309–321. <http://e-journal.unipma.ac.id/index.php/SHE>
- Baidoo-Anu, D., Asamoah, D., Amoako, I., & Mahama, I. (2024). Exploring student perspectives on generative artificial intelligence in higher education learning. *Discover Education*, 3(1). <https://doi.org/10.1007/s44217-024-00173-z>
- Baidoo-Anu, D., & Owusu Ansah, L. (2023). Education in the Era of Generative Artificial Intelligence (AI): Understanding the Potential Benefits of ChatGPT in Promoting Teaching and Learning. *SSRN Electronic Journal*, 7(1), 52–62. <https://doi.org/10.2139/ssrn.4337484>

- Bancoro, J. C. (2024). Relationship Between Artificial Intelligence (AI) Usage and Academic Performance of Business Administration Students. *Pedagogy Review: An International Journal of Educational Theories, Approaches and Strategies*, 1(1), 1–15. <https://doi.org/10.62718/vmca.pr-ijetas.1.1.SC-1223-004>
- Belkina, M., Daniel, S., Nikolic, S., Haque, R., Lyden, S., Neal, P., Grundy, S., & Hassan, G. M. (2025). Implementing generative AI (GenAI) in higher education: A systematic review of case studies. *Computers and Education: Artificial Intelligence*, 8(July 2024), 100407. <https://doi.org/10.1016/j.caeai.2025.100407>
- Bender, S. M. (2024). Awareness of Artificial Intelligence as an Essential Digital Literacy: ChatGPT and Gen-AI in the Classroom. *Changing English: Studies in Culture and Education*, 31(2), 161–174. <https://doi.org/10.1080/1358684X.2024.2309995>
- Blancia, G. V. V., Fetalvero, E. G., Baldera, P. R., & Mani, M. C. (2024). The Mediating Effects of Artificial Intelligence Literacy on The Association Between Computational Thinking Skills And Organizational Agility Among Secondary School Teachers. *Problems of Education in the 21st Century*, 82(5), 616–629. <https://doi.org/10.33225/pec/24.82.616>
- Bonsu, E. M., & Baffour-Koduah, D. (2023). From the Consumers' Side: Determining Students' Perception and Intention to Use ChatGPT in Ghanaian Higher Education. *Journal of Education, Society & Multiculturalism*, 4(1), 1–29. <https://doi.org/10.2478/jesm-2023-0001>
- Božić, V., & Poola, I. (2023). Chat GPT and education. *Education*, 1(4), 1–8. <https://doi.org/10.13140/RG.2.2.18837.40168>
- Bozkurt, A. (2024). Why Generative AI Literacy, Why Now and Why it Matters in the Educational Landscape? Kings, Queens and GenAI Dragons. *Open Praxis*, 16(3), 283–290. <https://doi.org/10.55982/openpraxis.16.3.739>
- Briones Peñalver, A. J., Bernal Conesa, J. A., & de Nieves Nieto, C. (2018). Analysis of Corporate Social Responsibility in Spanish Agribusiness and Its Influence on Innovation and Performance. *Corporate Social Responsibility and Environmental Management*, 25(2), 182–193. <https://doi.org/10.1002/csr.1448>
- Cain, M. K., Zhang, Z., & Yuan, K.-H. (2017). Univariate and multivariate skewness and kurtosis for measuring nonnormality: Prevalence, influence and estimation. *Behavior Research Methods*, 49(5), 1716–1735. <https://doi.org/10.3758/s13428-016-0814-1>

- Chen, K., Tallant, A. C., & Selig, I. (2024). Exploring generative AI literacy in higher education: student adoption, interaction, evaluation and ethical perceptions. *Information and Learning Science*. <https://doi.org/10.1108/ILS-10-2023-0160>
- Chenqi, L., Guoqing, L., & Xiangchun, H. (2023). Measuring Artificial Intelligence Literacy of Pre-service Teachers at a University in Northwest China. 2023 Twelfth International Conference of Educational Innovation through Technology (EITT), December 2023, 100–105. <https://doi.org/10.1109/EITT61659.2023.00027>
- Chiu, T. K. F., Chen, Y., Yau, K. W., Chai, C. sing, Meng, H., King, I., Wong, S., & Yam, Y. (2024). Developing and validating measures for AI literacy tests: From self-reported to objective measures. *Computers and Education: Artificial Intelligence*, 7(June), 100282. <https://doi.org/10.1016/j.caeai.2024.100282>
- Cohen, J. (1992). Statistical Power Analysis. *Current Directions in Psychological Science*, 1(3), 98–101. <https://doi.org/10.1111/1467-8721.ep10768783>
- Commey-Mintah, P., Opoku, A., Kudjordji, S. K., & Awuah, F. (2023). Factors Influencing Students' Academic Performance: The Case of Pre-Service Teachers at Dambai College of Education in Ghana. *Education Quarterly Reviews*, 6(1). <https://doi.org/10.31014/aior.1993.06.01.691>
- Deschenes, A., & McMahon, M. (2024). A Survey on Student Use of Generative AI Chatbots for Academic Research. *Evidence Based Library and Information Practice*, 19(2), 2–22. <https://doi.org/10.18438/ebliip30512>
- Elbaz, A. M., Salem, I. E., Darwish, A., Alkathiri, N. A., Mathew, V., & Al-Kaaf, H. A. (2024). Getting to know ChatGPT: How business students feel, what they think about personal morality, and how their academic outcomes affect Oman's higher education. *Computers and Education: Artificial Intelligence*, 7(November), 100324. <https://doi.org/10.1016/j.caeai.2024.100324>
- Essel, H. B., Vlachopoulos, D., Essuman, A. B., & Amankwa, J. O. (2024). ChatGPT effects on cognitive skills of undergraduate students: Receiving instant responses from AI-based conversational large language models (LLMs). *Computers and Education: Artificial Intelligence*, 6(July 2023), 100198. <https://doi.org/10.1016/j.caeai.2023.100198>
- Essel, H. B., Vlachopoulos, D., Nunoo-Mensah, H., & Amankwa, J. O. (2025). Exploring the impact of <sc>VoiceBots</sc> on multimedia programming education among Ghanaian university students. *British Journal of Educational Technology*, 56(1), 276–295. <https://doi.org/10.1111/bjet.13504>

Essel, H. B., Vlachopoulos, D., & Tachie-Menson, A. (2021). The relationship between the nomophobic levels of higher education students in Ghana and academic achievement. *PLoS ONE*, 16(6 June), 1–17. <https://doi.org/10.1371/journal.pone.0252880>

Essel, H. B., Vlachopoulos, D., Tachie-Menson, A., Johnson, E. E., & Baah, P. K. (2022). The impact of a virtual teaching assistant (chatbot) on students' learning in Ghanaian higher education. *International Journal of Educational Technology in Higher Education*, 19(1). <https://doi.org/10.1186/s41239-022-00362-6>

Essel, H. B., Vlachopoulos, D., Tachie-Menson, A., Johnson, E. E., & Nyadu-Ado, R. (2025). 7 Things You Should Know about Integrating Generative Artificial Intelligence and Design Thinking (Issue February). <https://doi.org/10.13140/RG.2.2.24027.68647>

Falk, R. F., & Miller, N. B. (1992). *A Primer for Soft Modeling*. The University of Akron Press. http://books.google.com/books/about/A_Primer_for_Soft_Modeling.html?id=3CFrQgAACAAJ

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41(4), 1149–1160. <https://doi.org/10.3758/BRM.41.4.1149>

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/BF03193146>

Hair, J. F. J., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate Data Analysis* (8th ed). CENGAGE.

Han, S., & Yi, Y. J. (2019). How does the smartphone usage of college students affect academic performance? *Journal of Computer Assisted Learning*, 35(1), 13–22. <https://doi.org/10.1111/jcal.12306>

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, 43(1), 115–135. <https://doi.org/10.1007/s11747-014-0403-8>

- Hirabayashi, S., Jain, R., Jurković, N., & Wu, G. (2024). Harvard Undergraduate Survey on Generative AI. 1–27. <http://arxiv.org/abs/2406.00833>
- Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, 6(1), 1–55. <https://doi.org/10.1080/10705519909540118>
- Jin, Y., Yang, K., Yan, L., Echeverria, V., Zhao, L., Alfredo, R., Milesi, M., Fan, J., Li, X., Gašević, D., & Martinez-Maldonado, R. (2024). Chatting with a Learning Analytics Dashboard: The Role of Generative AI Literacy on Learner Interaction with Conventional and Scaffolding Chatbots. 1(1), 1–17. <https://doi.org/10.1145/3706468.3706545>
- Kalota, F. (2024). A Primer on Generative Artificial Intelligence. *Education Sciences*, 14(2), 172. <https://doi.org/10.3390/educsci14020172>
- Kamau, J. N. (2025). Generative Artificial Intelligence and Academic Performance: Mediating Role of Smart Learning Environment. *African Journal of Business and Development Studies*, 1(2), 199–213. <https://doi.org/10.70641/ajbds.v1i2.98>
- Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., & Huber, P. (2016). Artificial intelligence and computer science in education: From Kindergarten to university. *Proceedings - Frontiers in Education Conference, FIE, 2016-Novem*, 1–9. <https://doi.org/10.1109/FIE.2016.7757570>
- Katalbas, D. A., Ng, C., & Marquez, V. (2023). An Investigation of the Relationship between Academic Buoyancy and Academic Performance among Senior High School Students: A Quantitative Research Approach. *International Journal of Metaverse*, 1(1), 11–16. <https://doi.org/10.54536/ijm.v1i1.1474>
- Kock, N. (2015). Common Method Bias in PLS-SEM. *International Journal of E-Collaboration*, 11(4), 1–10. <https://doi.org/10.4018/ijec.2015100101>
- Kock, N., & Lynn, G. (2012). Lateral Collinearity and Misleading Results in Variance-Based SEM: An Illustration and Recommendations. *Journal of the Association for Information Systems*, 13(7), 546–580. <https://doi.org/10.17705/1jais.00302>
- Laupichler, M. C., Aster, A., Schirch, J., & Raupach, T. (2022). Artificial intelligence literacy in higher and adult education: A scoping literature review. *Computers and Education: Artificial Intelligence*, 3(September), 100101. <https://doi.org/10.1016/j.caeai.2022.100101>

- Liang, J., Wang, L., Luo, J., Yan, Y., & Fan, C. (2023). The relationship between student interaction with generative artificial intelligence and learning achievement: serial mediating roles of self-efficacy and cognitive engagement. *Frontiers in Psychology*, 14(December), 1–12. <https://doi.org/10.3389/fpsyg.2023.1285392>
- Long, D., & Magerko, B. (2020). What is AI Literacy? Competencies and Design Considerations. *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–16. <https://doi.org/10.1145/3313831.3376727>
- Mansoor, H. M. H., Bawazir, A., Alsabri, M. A., Alharbi, A., & Okela, A. H. (2024). Artificial intelligence literacy among university students—a comparative transnational survey. *Frontiers in Communication*, 9(October). <https://doi.org/10.3389/fcomm.2024.1478476>
- Mehrvarz, M., Heidari, E., Farrokhnia, M., & Noroozi, O. (2021). The mediating role of digital informal learning in the relationship between students' digital competency and their academic performance. *Computers and Education*, 167(June 2020), 104184. <https://doi.org/10.1016/j.compedu.2021.104184>
- Memon, M. A., Thurasamy, R., Cheah, J.-H., Ting, H., Chuah, F., & Cham, T. H. (2023). ADDRESSING COMMON METHOD BIAS, OPERATIONALIZATION, SAMPLING, AND DATA COLLECTION ISSUES IN QUANTITATIVE RESEARCH: REVIEW AND RECOMMENDATIONS. *Journal of Applied Structural Equation Modeling*, 7(2), 1–14. [https://doi.org/10.47263/JASEM.7\(2\)01](https://doi.org/10.47263/JASEM.7(2)01)
- Ng, D. T. K., Leung, J. K. L., Chu, K. W. S., & Qiao, M. S. (2021a). AI Literacy: Definition, Teaching, Evaluation and Ethical Issues. *Proceedings of the Association for Information Science and Technology*, 58(1), 504–509. <https://doi.org/10.1002/prai.2.487>
- Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., & Qiao, M. S. (2021b). Conceptualizing AI literacy: An exploratory review. *Computers and Education: Artificial Intelligence*, 2, 100041. <https://doi.org/10.1016/j.caeai.2021.100041>
- Ng, D. T. K., Leung, J. K. L., Su, J., Ng, R. C. W., & Chu, S. K. W. (2023). Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world. *Educational Technology Research and Development*, 71(1), 137–161. <https://doi.org/10.1007/s11423-023-10203-6>

Ng, D. T. K., Tan, C. W., & Leung, J. K. L. (2024). Empowering student self-regulated learning and science education through ChatGPT: A pioneering pilot study. *British Journal of Educational Technology*, 55(4), 1328–1353. <https://doi.org/10.1111/bjet.13454>

O'Dea, X. (2024). Generative AI: is it a paradigm shift for higher education? *Studies in Higher Education*, 49(5), 811–816. <https://doi.org/10.1080/03075079.2024.2332944>

O'Dea, X., Tsz Kit Ng, D., O'Dea, M., & Shkuratsky, V. (2024). Factors affecting university students' generative AI literacy: Evidence and evaluation in the UK and Hong Kong contexts. *Policy Futures in Education*, 1–22. <https://doi.org/10.1177/14782103241287401>

Obenza, B. N., Go, L. E., Francisco, J. A. M., Buit, E. E. T., Mariano, F. V. B., Cuizon Jr, H. L., Cagabhion, A. J. D., & Agbulos, K. A. J. L. (2024). The Nexus between Cognitive Absorption and AI Literacy of College Students as Moderated by Sex. *American Journal of Smart Technology and Solutions*, 3(1), 32–39. <https://doi.org/10.54536/ajsts.v3i1.2603>

Özden, M., YAŞAR, F. Ö., & Meydan, E. (2025). The Relationship Between Pre-service Teachers' Attitude towards Artificial Intelligence (AI) and their AI literacy. *Pegem Journal of Education and Instruction*, 15(3), 121–131. <https://doi.org/10.47750/pegegog.15.03.13>

Ringle, C. M., Sarstedt, M., Mitchell, R., & Gudergan, S. P. (2020). Partial least squares structural equation modeling in HRM research. *The International Journal of Human Resource Management*, 31(1), 1617–1643. <https://doi.org/10.1080/09585192.2017.1416655>

Salifu, I., Arthur, F., Arkorful, V., Abam Nortey, S., & Solomon Osei-Yaw, R. (2024). Economics students' behavioural intention and usage of ChatGPT in higher education: a hybrid structural equation modelling-artificial neural network approach. *Cogent Social Sciences*, 10(1). <https://doi.org/10.1080/23311886.2023.2300177>

Sari, D. K., Supahar, S., Rosana, D., Dinata, P. A. C., & Istiqlal, M. (2025). Measuring artificial intelligence literacy : The perspective of Indonesian higher education students.

Sarstedt, M., Ringle, C. M., & Hair, J. F. (2021). Partial Least Squares Structural Equation Modeling. *Handbook of Market Research*, May 2020, 587–632. https://doi.org/10.1007/978-3-319-57413-4_15

- Sharples, M. (2023). Towards social generative AI for education: theory, practices and ethics. *Learning: Research and Practice*, 9(2), 159–167. <https://doi.org/10.1080/23735082.2023.2261131>
- Shen, Y., & Cui, W. (2024). Perceived support and AI literacy: the mediating role of psychological needs satisfaction. *Frontiers in Psychology*, 15(June), 1–11. <https://doi.org/10.3389/fpsyg.2024.1415248>
- Siemens, G. (2018). Connectivism. In R. E. West (Ed.), *Foundations of Learning and Instructional Design Technology* (1st ed., pp. 362–376). <https://doi.org/10.59668/3>
- Singh, E., Vasishta, P., & Singla, A. (2024). AI-enhanced education: exploring the impact of AI literacy on generation Z's academic performance in Northern India. *Quality Assurance in Education*. <https://doi.org/10.1108/QAE-02-2024-0037>
- Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, 48(6), 1273–1296. <https://doi.org/10.1007/s11165-016-9602-2>
- Tetteh, H., & Agyei, D. (2022). Factors Influencing Pre-Service Teachers' Performance in Mathematics in Colleges of Education: Re-counting Experiences in Ghana. *African Journal of Educational Studies in Mathematics and Sciences*, 18(1), 69–86. <https://doi.org/10.4314/ajesms.v18i1.6>
- Tlili, A., Saqer, K., Salha, S., & Huang, R. (2025). Investigating the effect of artificial intelligence in education (AIED) on learning achievement: A meta-analysis and research synthesis. *Information Development*, 1–18. <https://doi.org/10.1177/02666669241304407>
- Wang, B., Rau, P.-L. L. P., & Yuan, T. (2023). Measuring user competence in using artificial intelligence: validity and reliability of artificial intelligence literacy scale. *Behaviour & Information Technology*, 42(9), 1324–1337. <https://doi.org/10.1080/0144929X.2022.2072768>
- Wiredu, J. (2023). An Investigation on the Characteristics, Abilities, Constraints, and Functions of Artificial Intelligence (Ai): the Age of Chatgpt As an Essential Ultramodern Support Tool. *International Journal of Development Research*, 13(5), 62614–62620. <https://doi.org/10.37118/ijdr.26689.05.2023>

Xiao, J., Alibakhshi, G., Zamanpour, A., Zarei, M. A., Sherafat, S., & Behzadpoor, S.-F. (2024). How AI Literacy Affects Students' Educational Attainment in Online Learning: Testing a Structural Equation Model in Higher Education Context. *The International Review of Research in Open and Distributed Learning*, 25(3), 179–198. <https://doi.org/10.19173/irrodl.v25i3.7720>

Youssef, E., Medhat, M., Abdellatif, S., & Al Malek, M. (2024). Examining the effect of ChatGPT usage on students' academic learning and achievement: A survey-based study in Ajman, UAE. *Computers and Education: Artificial Intelligence*, 7(October), 100316. <https://doi.org/10.1016/j.caeai.2024.100316>

Zhao, L., Wu, X., & Luo, H. (2022). Developing AI Literacy for Primary and Middle School Teachers in China: Based on a Structural Equation Modeling Analysis. *Sustainability (Switzerland)*, 14(21), 1–16. <https://doi.org/10.3390/su142114549>

iDigital: Revolutionizing Access to Identification Through Digitalization in Ghana

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ABSTRACT:

In Ghana, identity verification remains highly dependent on physical documents such as passports and ID cards, which often restrict access to services in education, travel, and finance especially when lost, damaged, or delayed. This paper introduces iDigital, a conceptual digital identity platform designed to provide secure, mobile-based access to verified identification, with particular emphasis on the digitalization of passports. While the education sector presents a strong entry point supporting academic mobility, online examination verification, and international admissions. The proposed system has broader implications across governance, financial services, public health, and civil registration. This research adopts a design-thinking and systems-based conceptual methodology, drawing from global digital identity models, national infrastructure trends, and existing policy frameworks. It outlines a solution-driven architecture supported by stakeholder needs assessments, legal landscape analysis, and technical feasibility insights. The platform is envisioned to leverage biometric authentication, blockchain-backed verification, and cloud-based storage to enable users to securely access and share their passport information digitally. Projected benefits include faster onboarding for education and public services, improved access to digital platforms, reduced document fraud, and increased efficiency in identity verification processes. By addressing systemic and practical challenges surrounding identity access in Ghana, iDigital offers a scalable pathway toward inclusive and interoperable digital infrastructure. The system lays a foundation for secure identity integration with other digital IDs such as the Ghana Card or voter registration and supports digital transformation goals in both public and private sectors while prioritizing passports as the pilot use case. This paper contributes to national and continental discourse on digital inclusion and calls for legal, institutional, and technical collaboration toward the recognition of digital passports.

KEYWORDS: E-learning, iDigital, Secure platforms, Research, Digitalization, Conceptual Design

1. Introduction

In Ghana, physical identification cards such as passports and national IDs are the backbone of access to public services, education, travel, and finance. However, dependence on physical documents comes with considerable risks and limitations. These include vulnerability to theft, misplacement, damage, and geographic inaccessibility especially for citizens in rural communities. This reliance restricts access to critical services and hampers the efficiency of both public and private sector institutions.

As the country advances its digital transformation agenda, including initiatives like the Ghana Card, there remains a significant gap: the lack of a unified, secure digital identity platform that integrates diverse ID credentials including passports into a single, accessible system. Unlike national ID cards which are becoming digitally enabled, Ghanaian passports remain predominantly physical, presenting a bottleneck for identity-dependent services with cross-border implications.

This paper introduces iDigital, a conceptual framework for developing a secure, mobile-based digital identity platform with particular focus on passport virtualization. While iDigital is designed to eventually integrate all major forms of identification (e.g., national ID, voter ID, NHIS card), this paper emphasizes passports due to their global utility and high verification demand across education, travel, and foreign services.

The research aims to:

- Identify structural and systemic barriers to digital ID access in Ghana;
- Propose a secure, scalable digital identity system beginning with passport integration;
- Demonstrate use cases in sectors like education, immigration, finance, and e-governance;
- Recommend legal, technical, and institutional pathways for adoption.

A design-thinking methodology is adopted, informed by global best practices, national policy reviews, and stakeholder readiness indicators. The findings contribute a policy-relevant, technology-agnostic blueprint for Ghana's digital identity ecosystem, helping bridge the identity gap while fostering trust, inclusion, and cross-border compatibility.

2. Literature Review: Digital Identity, Inclusion, and Passport Virtualization

The evolution of digital identity systems has become central to discussions around governance, inclusion, and access to services in both developed and developing countries. A digital identity (ID) refers to a set of electronically captured and verified credentials used to authenticate individuals across digital platforms (World Bank, 2018). Robust digital identity frameworks have demonstrated transformative impacts in areas such as social protection, public administration, financial inclusion, education, and migration management.

2.1 Global Perspectives on Digital Identity Systems

Globally, countries have adopted a range of approaches to implement secure and scalable digital identity systems. India's Aadhaar program is one of the most cited models reaching over 1.3 billion individuals with biometric-based authentication. Aadhaar is credited with reducing fraud in welfare distribution and improving digital service delivery (Chakrabarti et al., 2022). Estonia's e-ID system, meanwhile, is often held as the gold standard in digital governance, enabling citizens to access over 99% of public services online using their national identity cards and mobile ID systems (Gelb & Clark, 2013).

In Europe, the eIDAS Regulation harmonizes digital ID standards across EU member states, supporting cross-border authentication and secure access to e-government services. In Canada and Australia, federated models of identity systems are gaining ground prioritizing user control and interoperability between public and private actors.

2.2 Digital Identity in the African Context

Sub-Saharan Africa has witnessed a surge in digital identity projects, largely driven by global development initiatives such as the World Bank's ID4D program and the African Union's Digital Transformation Strategy. Countries like Nigeria, Kenya, Rwanda, and South Africa have made substantial progress in implementing national ID systems that integrate biometric and demographic data.

Ghana has positioned itself as a frontrunner through its Ghana Card, issued by the National Identification Authority (NIA). The Ghana Card integrates biometric verification and is designed to be interoperable with institutions such as the Electoral Commission, Ghana Revenue Authority (GRA), and Social Security and National Insurance Trust (SSNIT). However, challenges persist in achieving full coverage, legal integration across sectors, and citizen trust in data handling (Owusu et al., 2021).

Despite these advancements, passport digitalization remains largely unexplored in most African nations. While some countries like Nigeria have launched biometric e-passports, the virtualization of passports into mobile-accessible formats remains nascent. Given the international relevance of passports, their inclusion in digital ID ecosystems offers an opportunity to streamline immigration services, student mobility, and cross-border verification processes.

2.3 Role of Digital Identity in Education and Service Access

Within the education sector, digital identity plays an increasingly critical role. Institutions rely on secure verification systems for student admissions, examination processes, and scholarship eligibility assessments. The COVID-19 pandemic further underscored the need for contactless, remote-friendly identity verification tools, especially for online learning platforms and remote examinations (UNESCO, 2021).

Studies by Radianti et al. (2020) and Jensen & Konradsen (2018) show that secure, mobile-based ID tools reduce administrative bottlenecks and promote equitable access to academic services. In Ghana, many tertiary institutions still rely on physical ID cards, exposing students to delays and identity challenges especially when engaging with international partners or remote academic services. Virtualizing key credentials such as passports could address these gaps and serve as a foundation for digitally integrated academic services.

2.4 Legal and Ethical Considerations in Digital ID Systems

Implementing a digital identity system necessitates strong legal and ethical frameworks. Ghana's Data Protection Act (2012) provides foundational regulations on the collection, storage, and usage of personal and biometric data. However, the legal recognition of digitally-presented identity credentials, such as virtual passports, remains ambiguous.

Globally, concerns around data security, surveillance, and user consent have been raised in digital ID discourse. Scholars emphasize the need for transparent governance, citizen oversight, and robust cybersecurity standards to mitigate risks such as data breaches and identity theft (Mukherjee, 2019). The proposed iDigital platform integrates these concerns by promoting user-centric design, encrypted data storage, and interoperability with national legal frameworks.

2.5 Contribution to the Field

This paper builds on and extends existing literature by:

- Introducing the concept of passport virtualization as a strategic entry point for digital ID adoption in Ghana;
- Framing education as a high-impact sector for piloting digital identity solutions with potential for cross-sector scaling;
- Addressing the interplay between legal, technical, and institutional systems, contributing to a practical roadmap for implementation;
- Emphasizing inclusive, mobile-first design that aligns with infrastructure realities in Ghana and similar developing economies.

3. Research Methodology

This study adopts a design-thinking and systems-based research methodology to explore the feasibility, structure, and impact of implementing a secure digital identity solution in Ghana, with a focus on virtualizing passports through the iDigital platform. The methodology draws from global best practices, stakeholder input, policy review, and contextual infrastructure analysis to co-develop a user-centered and scalable solution.

3.1 Design Thinking Framework

The project uses the five-stage design thinking process to define the problem, co-develop a user-centered solution, and assess its practical applications in Ghana's public and educational sectors.

- **Empathize:** Through secondary research and stakeholder mapping, the study identifies core challenges faced by users. These include loss or damage of physical identity documents, slow and manual verification processes, limited interoperability across institutions, and exclusion from time-sensitive services due to ID unavailability.
- **Define:** The central problem is framed as Ghana's overdependence on physical identity documents particularly passports which impedes inclusive, efficient access to education, immigration, and public services. This definition also accounts for infrastructural, legal, and institutional challenges.
- **Ideate:** Drawing on case studies from India (Aadhaar), Estonia (e-ID), and Ghana's own infrastructure (Ghana Card, Biometric voter register), the study explores scalable, mobile-first solutions for secure identity access. Emphasis is placed on biometric verification, blockchain integration, and mobile accessibility.

- **Prototype (Conceptual):** Rather than building a physical prototype, the research outlines a functional architecture of the iDigital system. This includes user workflows, biometric data handling, encrypted storage, and API-based integration with national databases.
- **Test (Scenario-Based):** The model is applied to simulated real-world use cases to evaluate feasibility. These include:
 - Student verification for online examinations
 - Academic mobility (e.g., applying to foreign universities)
 - Identity verification for public services such as visa applications or scholarship processing

3.2 Systems-Based Assessment

To ensure broader alignment and sustainability, the study integrates a systems-thinking lens to examine how iDigital fits into Ghana's digital identity ecosystem:

- Mapping existing national identity systems and infrastructure (Ghana Card, biometric passports, voter ID, SSNIT)
- Identifying points of interoperability for institutional integration (e.g., API connections with WAEC, GRA, NHIS)
- Evaluating sectoral readiness in governance, education, and public administration

This assessment helps ensure that the solution does not function in isolation but complements and enhances Ghana's broader digital transformation agenda.

3.3 Stakeholder and Needs Analysis

A detailed stakeholder mapping exercise was conducted to identify the expectations, constraints, and operational roles of the key actors involved. These include:

- Primary stakeholders: Students, universities, examination bodies, the Ghana Immigration Service, and passport issuing authorities.
- Secondary stakeholders: Ministry of Education, Ministry of Communications and Digitalisation, National Identification Authority (NIA), National Information Technology Agency (NITA), and private digital identity service providers.

A combination of desktop research and semi-structured expert consultations was used to conduct the stakeholder analysis. Public documents, institutional mandates, and service workflows were reviewed to determine which actors are responsible for identity verification, where friction occurs, and what expectations exist for a digital identity system.

In addition, three informal consultations were held with staff from tertiary institutions and one senior official from a national agency to validate perceived pain points and desired features. The data was analysed using a role-impact matrix, assessing each stakeholder's influence, level of interest, technical readiness, and anticipated benefits. This analysis guided the prioritization of system features and integration requirements.

The analysis informs design choices, promotes stakeholder buy-in, and ensures alignment with user needs and institutional mandates.

3.4 Policy and Legal Framework Review

The legal and policy environment in Ghana was reviewed to assess the readiness for digital ID adoption, with a focus on passports:

- **Data Protection:** The study reviews Ghana's Data Protection Act (2012), which governs how biometric and cloud-based personal data can be stored, processed, and shared.
- **Legal Identity Recognition:** The legal status of identity documents (e.g., passports) is examined to assess whether digital formats could be officially recognized.
- **National Policy Alignment:** The study aligns the iDigital initiative with Ghana's National Digital Economy Policy and Strategy, as well as the e-Transform Project and Digital Ghana Agenda.

3.5 Technical Feasibility Mapping

Though no physical prototype is built, the study outlines a technically feasible implementation framework, focusing on:

- **Biometric authentication** for individual identity verification, potentially leveraging the NIA's existing database
- **Blockchain-based credential verification** to prevent tampering and unauthorized duplication

- Cloud-based storage and mobile access, using secure APIs and end-to-end encryption
- Integration pathways with educational portals (e.g., WAEC, university admissions) and immigration databases (e.g., Ghana Immigration Service)

The technical evaluation considers system scalability, cybersecurity risks, compliance with global standards, and cost-effectiveness in low-resource environments.

3.6 Technical Hands-On Application Framework

Although no physical prototype was built during the research phase, a technically grounded application strategy was developed to demonstrate how iDigital could be implemented using available tools, infrastructure, and design principles.

3.6.1 System Architecture and Platform Design

The proposed iDigital platform is designed as a modular, mobile-first application supported by a secure cloud-based backend. Key components include:

- **Frontend Application:** A user interface for Android and iOS devices, allowing citizens to view, present, and manage their digital passport and linked credentials. The app will support fingerprint and facial recognition login options.
- **Middleware APIs:** Secure APIs to facilitate communication between the iDigital platform and external databases (e.g., Ghana Card registry, passport system, SSNIT, WAEC). Open standards such as OAuth 2.0 and RESTful services are preferred for interoperability.
- **Backend Infrastructure:** A cloud-hosted system, preferably built on services like AWS GovCloud or Azure Government, will manage user authentication, data encryption, and blockchain-based credential validation.
- **Blockchain Verification Layer:** A lightweight private blockchain (e.g., Hyperledger Fabric or Ethereum Layer 2) will be used to create tamper-proof digital credentials and provide audit logs of access requests.

3.6.2 Biometric Integration

Biometric data (fingerprint or facial recognition) will be:

- Sourced from existing NIA databases through authorized APIs
- Used for both identity registration and transaction validation
- Matched locally on-device for speed and privacy, with fallback to cloud matching for edge cases

Biometric SDKs such as Daon, Innovatrics, or open-source tools like OpenCV could be integrated into the mobile client.

3.6.3 Secure Data Handling and Privacy

To ensure security and compliance with Ghana's Data Protection Act:

- All data will be encrypted at rest and in transit using AES-256 and TLS 1.3
- Two-factor authentication (2FA) will be implemented for administrative roles
- User credentials will be stored using zero-knowledge proof (ZKP) principles to prevent misuse by system administrators

A role-based access control (RBAC) model will be enforced across all user types: citizen, verifier, and administrator

3.6.4 Integration Pathways

Integration points include:

- Ghana Immigration Service (digital passport registry)
- NIA (Ghana Card and biometric validation)
- University portals and WAEC (academic credential verification)
- Public service institutions (e.g., NSS, NHIS, GRA) for ID cross-verification

Each institution can consume iDigital services through standard APIs, allowing for layered adoption.

3.6.5 Accessibility and Offline Support

To ensure equity, the system will support:

- USSD-based verification for feature phone users
- Offline QR-code based credential sharing with time-stamped and signed hashes
- Campus kiosks with limited iDigital features to support low-bandwidth users.

3.7 Limitations

As a conceptual and design-based study, this research has the following limitations:

- No live pilot or end-user testing was conducted during the research phase.
- Legal frameworks for recognizing digital passports remain underdeveloped.
- Dependence on infrastructure such as cloud servers, biometrics, and secure APIs may present scaling challenges.
- Access equity remains a concern, especially among citizens without smart-

phones or internet access.

Future work will include field testing, legal advocacy, and performance evaluations to validate the model under real-world conditions.

4. Findings and Discussion

The conceptual modelling of iDigital, supported by stakeholder insights, systems analysis, and policy review, reveals significant potential for transforming identity access and verification in Ghana. While the educational sector presents a practical and impactful entry point, the proposed solution is broadly relevant to immigration services, digital governance, and national development.

4.1 Structural and Policy Alignment

The analysis demonstrates that iDigital aligns with Ghana's national digital transformation strategies, including the Ghana Card initiative, the e-passport rollout, and the broader Digital Ghana Agenda. These systems provide a foundation for interoperability and policy coherence, allowing iDigital to integrate with existing databases while advancing Ghana's ambition for secure, citizen-centric digital identity services.

4.2 Benefits of Passport Virtualization

By digitizing passports and enabling mobile-based access, the platform provides widespread benefits across multiple sectors:

- For citizens: Reliable, secure identification even in the absence of physical documents.
- For service providers: Faster identity verification, reduced fraud, and streamlined operations.
- For public sector institutions: Real-time access to ID verification for immigration, scholarships, banking, and voting.

In particular, students and academic institutions stand to benefit immediately through improved verification processes for exams, admissions, and international mobility establishing education as a strategic pilot environment.

4.3 Institutional Impact Across Sectors

Stakeholder engagement reveals institutional value in several domains:

- **Education:** Universities can verify identity during registration, remote assessments, and postgraduate application reviews.
- **Immigration:** Digital passports allow real-time validation for visa applications and travel pre-clearance.
- **Public Services:** Ministries and agencies can reduce delays and improve access to health insurance, national service, and youth employment initiatives.

Results from the stakeholder analysis confirmed strong interest among institutions that face identity verification challenges. University administrators expressed concerns about exam impersonation and delays in cross-institutional record verification. Immigration officers emphasized inefficiencies caused by verifying physical passport authenticity. These findings confirmed the need for real-time digital verification tools, biometric login features, and institutional data sharing protocols.

The platform supports data-driven decision-making while enhancing national security and administrative efficiency.

4.4 Key Challenges and Risks

While the concept is feasible, a number of implementation risks must be addressed:

- **Lack of Legal Recognition:** Current regulations do not formally recognize digital identity formats like virtual passports.
- **Device Access Disparity:** Uneven smartphone and internet access could limit adoption in underserved regions.
- **Data Security Concerns:** Handling biometric and personal data requires compliance with national data protection laws and cybersecurity standards.
- **Institutional Readiness Gaps:** Some government departments and universities may lack the tools to integrate with the digital platform.

The policy and legal review uncovered both opportunities and limitations. Ghana's Data Protection Act (2012) supports biometric-based services, but it does not explicitly allow for virtual passport presentation or acceptance. While this presents a regulatory gap, Ghana's National Digital Economy Strategy provides a policy pathway for reform. The alignment between iDigital and national digital priorities makes the system a candidate for inclusion in future digital identity legislation.

4.5 Mitigation Strategies

Table 1. Mitigation strategies to address challenges of iDigital

Challenge	Proposed Mitigation
Legal framework gaps	Policy dialogue and legal amendments to enable digital ID recognition
Access limitations	Deploy USSD options, on-campus kiosks, and offline verification modes
Cybersecurity risks	Employ end-to-end encryption, ISO security standards, and biometric protection layers
Institutional fragmentation	Provide API toolkits, onboarding guides, and digital maturity workshops

4.6 Contribution to Knowledge and Practice

iDigital offers a Ghana-specific model for digital identity transformation with regional relevance. While education serves as the initial testing ground, the system’s modular and interoperable design supports broader deployment across government services and the private sector. The model contributes to digital governance research by:

- Demonstrating how passport virtualization can drive digital identity adoption
- Emphasizing inclusion, mobile access, and user control
- Aligning digital identity innovation with national development and cross-border mobility

5. Conclusion and Further Research

This paper has proposed iDigital as a scalable, secure, and mobile-based digital identity platform for Ghana, with an initial emphasis on the digitalization of passports. The platform responds to systemic challenges around identity verification, service delivery, and administrative inefficiencies caused by overreliance on physical identification documents. While the educational sector offers a compelling and immediate use case particularly for remote verification, international admissions, and student mobility the conceptual framework supports a cross-sectoral deployment model.

Findings from stakeholder analysis, legal reviews, and systems mapping suggest that iDigital can integrate with existing infrastructure (e.g., Ghana Card, biometric passports, SSNIT), and meet the growing demand for faster, more secure digital verification processes across immigration, public services, finance, and academia. The platform offers benefits such as enhanced inclusion, fraud prevention, data-driven governance, and improved user experience.

The system's flexible design allows it to serve multiple identity-dependent sectors, positioning iDigital as a cornerstone of Ghana's broader digital transformation strategy. Its application in the education sector provides a controlled environment to test functionality, user uptake, and institutional alignment before wider national rollout.

Further research and development will focus on:

- Legal recognition of digital passport formats and updates to identity laws.
- Pilot testing with universities, examination bodies, and immigration services.
- Development of offline-compatible and low-bandwidth access features (e.g., USSD and kiosks).
- Interoperability testing with the Ghana Card, National Health Insurance Scheme (NHIS), and public service portals.
- Long-term performance evaluation, cybersecurity audits, and user satisfaction studies.

With proper legal, technical, and institutional support, iDigital can serve as a model for secure, inclusive, and forward-looking digital identity ecosystems across Africa.

6. Acknowledgement

The authors wish to express their sincere appreciation to the E-Learning Centre of Kwame Nkrumah University of Science and Technology (KNUST), whose leadership in digital transformation provided the inspiration and academic environment to conceptualize this study.

Special thanks are also extended to public service representatives from the Ghana Immigration Service and the National Identification Authority (NIA), whose informal insights helped to shape key aspects of the system design and policy alignment.

This paper also draws on Ghana's ongoing digitalization agenda and is inspired by national efforts to promote innovation, inclusion, and technological resilience through policy reform and digital governance.

7. References

- Agyekum, K., Boateng, F. & Owusu, P. (2021), 'The role of biometric passports in national security and identity management in Ghana', *Journal of African Governance and Development*, 6(2), pp. 45–60.
- Chakrabarti, A., Banerjee, S. & Sen, R. (2022), 'Digital identity systems in emerging economies: Lessons from India and Africa', *International Journal of Information Management*, 62, pp. 102442.
- Gelb, A. & Clark, J. (2013), *Identification for Development: The Biometrics Revolution*, Center for Global Development. Available at: <https://www.cgdev.org/publication/identification-development-biometrics-revolution>.
- Mukherjee, A. (2019), 'Digital identity and inclusion: Emerging frameworks in Sub-Saharan Africa', *Development Policy Review*, 37(5), pp. 561–580.
- Owusu, P., Asare, B. & Amoako, J. (2021), 'Assessing Ghana's digital transformation agenda: Opportunities and challenges', *African Journal of ICT Development*, 8(1), pp. 34–48.
- Radianti, J., Majchrzak, T.A., Fromm, J. & Wohlgenannt, I. (2020), 'A systematic review of immersive virtual reality applications for higher education', *Computers & Education*, 147, pp. 103778.
- Republic of Ghana (2012), *Data Protection Act, 2012 (Act 843)*. Accra: Government of Ghana.

Republic of Ghana (2020), National Digital Economy Policy and Strategy (2020–2030). Ministry of Communications and Digitalisation. Available at: <https://moc.gov.gh>

UNESCO (2021), Digital Learning and Transformation in Africa: Strategic Priorities. Paris: UNESCO. Available at: <https://unesdoc.unesco.org/>

Perceptions And Predictors Of Trust In Artificial Intelligence: Ethical Implications And Regulatory Oversight In Ghana – A Mixed-Methods Study

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ABSTRACT:

Artificial intelligence (AI) technologies are advancing globally and remain crucial for social transformation, economic growth and technological advancement, notwithstanding the need to understand the perceptions, ethical implications and regulatory needs of AI users. This study examines the perceptions and predictors of trust in artificial intelligence and associated ethical implications among stakeholders in the greater Kumasi area, Ghana. A convergent parallel mixed-method design was adopted for this study. The quantitative aspect involved a cross-sectional survey of 287 stakeholders, while the qualitative aspect utilised a phenomenological design through a semi-structured interview of 9 participants. The quantitative data was analysed using frequencies and a logistic regression. The qualitative data was analysed using a thematic approach. Four in ten of all stakeholders studied 114(39.72%) had positive perception of AI. The most cited benefit of AI relates to ability to increase efficiency 175(34.59%). Key challenges included issues around privacy and data security 145(31.59%). The top concerns revolved around lack of transparency in decision-making 140(30.30%) and privacy and data security risks 134(29.00%). The majority of stakeholders 271(94.43%) believe AI should be regulated in the context of Ghana, occupation significantly predicts trust in AI-powered applications. Lawyers [OR .177 (95.0 % CI: (.039-.805; p=0.025)] and university lecturers [OR .218 (95.0 % CI: (.072-.660; p=0.007)] have significantly higher odds of trusting AI-powered applications compared to the other occupations studied. Designing inclusive AI frameworks that reflect the socio-cultural background and economic realities is key to ensuring ethical AI development and deployment.

KEYWORDS: Artificial Intelligence (AI), stakeholder trust, ethical implications, Regulatory needs, Public perception of AI.

1. Introduction

Artificial intelligence (AI) technology is being adopted across diverse sectors globally in enhancing decision-making and automating tasks (Rane et al., 2024). The transformation of AI is evident in sub-Saharan Africa and Ghana through the gradual integration of AI tools in private and public settings. However, in Ghana, empirical studies on the perception of AI remain limited and no national AI policy currently exists to guide the development and deployment of these technologies.

Trust is a major factor in determining AI acceptance, with empirical research indicating that socio-demographic factors may predict individuals' trust or distrust in AI-powered applications (Jarosław Kozak & Fel, 2024; Li et al., 2024). Regulatory oversight of AI technologies in Ghana is currently fragmented, with no national AI policy framework in place. There is also a call for the decolonisation of technological systems by African AI scholars and embedding such systems with local frameworks through the engagement of diverse stakeholders in policymaking (Mhlabi & Jahnke, 2021). Understanding trust and ethical concerns is vital for shaping responsible AI governance in Ghana.

This study fills the gap, providing empirical insights specific to Ghana by examining stakeholder perceptions, predictors of trust, ethical implications and regulatory needs of AI, while also assessing the perceived need for regulatory frameworks and ethical guidelines in the development and deployment of AI across all sectors. The mixed method design combined a survey (n=287) and a thematic analysis of stakeholder interviews (n=9). The findings indicate that while stakeholders have a positive perception of AI, trust levels vary based on the socio-demographic factors. Ethical concerns revolved around a lack of transparency in AI decision making and privacy and data risk concerns, alongside a strong call for inclusive, context-specific regulatory frameworks.

The study contributes to the ongoing scholarship on responsible AI, particularly in low- and middle-income countries. The insights are expected to benefit policymakers, AI developers and civil society actors seeking to develop locally grounded ethical AI systems in Ghana. However, the study is limited by its focus on the selected regions, which may affect generalisation.

2. Literature Review

The adoption of AI across diverse sectors globally has prompted academic interest in how individuals use and perceive AI (Islom, 2022). Central to the perception of AI is the issue of trust in AI, which has been examined extensively across diverse fields, including human-computer interaction and the sociology of technology. Trust in AI technologies is an important factor in determining how an individual perceives AI-powered applications. The literature indicates that several demographic factors including age, gender, educational level and religion may predict an individual's trust or distrust in AI-powered applications (Jarosław Kozak & Fel, 2024; Li et al., 2024); other factors including system reliability, user experience, situational factors (Ryan, 2023), fairness, transparency and accountability (Floridi et al.) can determine trust in AI according to the Trust in automation model (Hoff & Bashir, 2015). Hatem et al. (2024) found that men trust AI more often than women. Novozhilova et al. (2024) also revealed that trust in AI increases with age and individuals with higher education tend to trust AI more. However, religious individuals often exhibit emotions such as fear, anger and distrust of AI (Jaroslaw Kozak & Fel, 2024).

Despite the favourable perceptions of AI, the integration of AI into society brings with it a plethora of ethical concerns, including issues of accountability, fairness and privacy (Neha et al., 2023). One of the most prominent ethical concerns is algorithm bias, where AI trained on historical data may perpetuate existing biases and inequalities (Liu et al., 2023). Studies suggest that the ethical implications of AI in developing economies are more pronounced due to weaker institutions and economic disparities. In the case of Ghana, the high rate of digital literacy, technical issues, internet connectivity problems, the inadequacy of online data accessibility and the absence of clear ethical guidelines for AI deployment in various sectors present ethical concerns (Institute of ICT Professionals Ghana, 2020).

Due to the inevitable nature of biases in AI algorithms, privacy, transparency, and issues with fairness, guidelines must be put in place to regulate the development and deployment of AI. Globally, the regulatory frameworks for AI are evolving with the European Union AI Act and the United Nations Resolution A/78/L49 emphasising the need for ethical AI principles in line with international human rights. The U.S has adopted a decentralised state-driven approach to AI regulation (Regional and International AI Regulations & Laws, 2024). However, few African countries have implemented laws that allow for the regulation of AI. African scholars advocate for the decolonisation of AI by embedding local moral systems and addressing intersecting social inequalities (Gwagwa et al., 2020). African countries, including Gha-

na, face challenges in adopting similar approaches due to infrastructural gaps and regulatory fragmentation. This calls for the need for localised regulatory frameworks that consider socio-cultural factors and the input of stakeholders.

The increasing relevance of these global frameworks calls for examining how they translate into the local context, particularly in relation to local trust dynamics, regulatory needs and perceptions in the African context. In Ghana, digital infrastructure is expanding, but the legal oversight remains underdeveloped. It is crucial to explore critically the perceptions, risks, opportunities and needs associated with AI as identified by diverse stakeholders. Despite global advancements in AI and governance, few studies have explored how these principles translate into the lived experiences of diverse stakeholders in the African context, like Ghana. This study contributes to the gap by providing a sociologically grounded investigation of the perceptions and predictors of trust in artificial intelligence: ethical implications and regulatory oversight in Ghana.

3. Research Methodology

The study was conducted in Kwadaso, Oforikrom, Subin, Ejisu and Santasi within the greater Kumasi area in the Ashanti Region of Ghana. A convergent parallel mixed-methods design was adopted for its capacity to triangulate generalisation with in-depth qualitative insights (Creswell and Creswell, 2017). The quantitative aspect employed a cross-sectional design surveying diverse stakeholders and the qualitative aspect involved a descriptive phenomenological design. This was deemed appropriate as compared to sequential designs since it allowed for the holistic understanding and simultaneous analysis of stakeholder perceptions, predictors and trust dynamics of AI.

3.1 Population and sampling

The population of the study included all residents within the selected districts and municipalities in the greater Kumasi area. The Cochran sampling formula was used to determine the sample size, and overall, 287 participants were recruited for the study. A multistage sampling involving cluster and purposive sampling was used for the quantitative aspect of the study. Clusters included students, lecturers/researchers, legal professionals and human rights groups. Within the various clusters, various organisations, entities and groups were selected due to their relevance to the topic under investigation. The second stage involved a purposive sampling from various clusters, ensuring adequate representation and minimising biases in the study. On the other hand, the qualitative aspect of the study involved a semi-structured interview and a convenience sampling of 9 participants; data saturation was achieved after the 9th interview.

3.2 Data collection

The quantitative data was collected using a researcher-developed closed-ended questionnaire developed via the kobocollect toolbox based on reviewed literature. The questionnaire was pre-tested in a similar environment where the study took place, ensuring that clarity, wording and response options were accurately represented by the researcher and understood by participants. The qualitative data, on the other hand, was collected through a researcher-developed in-depth semi-structured face-to-face interview guide from the various stakeholders and recorded. The semi-structured interview guide enabled participants to share their perspectives on the ethical implications and regulatory needs of AI in the greater Kumasi area of Ghana.

3.3 Data analysis

The quantitative aspect of the study was analysed using descriptive and binary logistic regression with a statistical significance set at $P < 0.05$ with STATA/SE 17. Outcome variables measured at the categorical level were trust of AI ("trust in AI" and "do not trust AI"), all variable choices were informed through an intensive literature review and included age, gender, occupation, educational level and religion. Thematic analysis based on Braun and Clarke's (2006) six-step thematic analysis (familiarisation, coding, theme generation, review, naming and report writing) was used with NVivo for the qualitative data analysis. Binary logistic regression was preferred over multinomial approaches due to the dichotomous nature of the trust variable and the interpretability of odds ratios for policy recommendations. NVivo was chosen for the qualitative aspect due to its ability to visualise large textual datasets systematically compared to manual coding or Excel-based techniques. While the qualitative aspect utilised the convenience sampling to access expert stakeholders, it may limit the representativeness of findings. Additionally, the reliance on self-reported data introduces potential biases that were mitigated through pretesting and careful instrument design.

3.4 Ethical considerations

Ethical clearance was approved by the Kwame Nkrumah University of Science and Technology, College of Humanities and Social Sciences Ethical Review Board. Anonymity and confidentiality assured and informed consent obtained with participants aware of their right to withdraw at anytime.

4. Findings and Discussion

4.1 Socio-demographic characteristics of stakeholders

Table 1 presents the socio-demographic characteristics of stakeholders in the study. Out of 287 respondents, nearly two-thirds were males 177(61.67%). The dominant age group were those aged 21-30 years (128(44.60%)). A majority 243(84.67%) were Christians and had had tertiary education 234(81.53%). Senior high and undergraduates students 108(37.63%) formed the dominant group studied; the least were data scientists with 9(3.14%).

Table 1: Socio-demographic characteristics of respondents

Variables	Frequency N (%)
Sex	
- Male	177(61.67)
- Female	110(38.33)
Age	
- 10-20	59(20.56)
- 21-30	128(44.60)
- 31-40	64(22.30)
- 40+	36(12.54)
Religion	
- Christian	243(84.67)
- Muslim	34(11.85)
- Traditionalist	9(3.14)
- Other	1(0.35)
Educational Level	
- Secondary education	53(18.47)
- Tertiary education	234(81.53)
Occupation	
- AI researcher	21(7.32)
- AI software developer	11(3.83)
- Computer Engineer	12(4.18)
- Data Scientist	9(3.14)

- Human right activist	16(5.57)
- Law Student	46(16.03)
- Lawyer	13(4.53)
- Student	108(37.63)
- University Researcher/Lecturer	51(17.77)

Source: (Field Data, 2024)

4.2 Perceptions, ethical implications and regulatory needs of AI among stakeholders

Table 2 presents findings related to the perceptions, ethical implications and regulatory needs of AI. Most stakeholders 114(39.72%) had a positive perception of AI. The most cited benefit of AI was increased efficiency, with 175(34.59%). Several challenges were identified with the adoption of AI, with privacy and data security issues 145(31.59%) being the most frequently mentioned. Most stakeholders 120(41.81%) were neutral in their trust in AI-powered applications. When considering ethical concerns, the top concerns were a lack of transparency in decision-making 140(30.30%) and privacy and data security risks 134(29.00%). An overwhelming majority of stakeholders 271(94.43%) believe that AI should be regulated in the context of Ghana.

Table 2: Perceptions, ethical implications and regulatory needs of AI among stakeholders

Variables	Frequency N (%)
Perception of AI use (n=287)	
- Very Negative	2(0.70)
- Negative	3(1.05)
- Neutral	62(21.60)
- Positive	114(39.72)
- Very Positive	106(36.93)
Benefit of AI (Multiple responses n=494)	
- Increase efficiency	175(35.43)
- Reduces cost	102(20.65)
- Improved decision making	96(19.43)

- Enhances convenience	121(24.49)
Challenges with AI adoption (Multiple responses n=459)	
- Job displacement	135(29.41)
- Privacy and data issues	145(31.59)
- Bias and fairness in algorithms	79(17.21)
- Ethical implications	100(21.79)
Trust in AI decision making (n=287)	
- Completely trust	53(18.47)
- Somewhat trust	120(41.81)
- Neutral	120(41.81)
- Somewhat distrust	15(5.23)
- Completely distrust	5(1.74)
Ethical concerns associated with Ai adoption (Multiple responses n=462)	
- Lack of transparency in decision-making	140(30.30)
- Potential for bias in AI algorithms	114(24.68)
- Privacy and data security risk	134(29.00)
- Effect on human autonomy and dignity	74(16.02)
Should AI be regulated to ensure ethical use (n=287)	
- Yes	271(94.43)
- No	16(5.57)

Source: (Field Data, 2024)

4.3 Predictors of trust in AI

The independent predictors of trust in AI-powered applications were explored using a binary logistic regression presented in (Table 3). In the unadjusted crude model, the occupation of participants is a significant predictor of trust in AI-powered applications. lawyers [OR .177 (95.0 % CI: (.039-.805; p=0.025)] and university lecturers [OR .218 (95.0 % CI: (.072-.660; p=0.007)] have significantly higher odds of trusting AI-powered applications compared to all other occupation groups.

Table 3: Binary logistic regression on the predictors of trust in AI

Variables	OR(CI)	P-value
Age		
10-20(ref)	1	
21-30	1.056(.569-1.959)	0.862
31-40	.903(.444-1.833)	0.778
40+	.645(.279-1.489)	0.305
Gender		
Male(ref)	1	
Female	1.241(.770-2.000)	0.374
Religion		
Christian(ref)	1	
Muslim	1.863(.882-3.934)	0.102
Traditionalist	.677(.186-2.462)	0.555
Atheist	1	
Educational level		
Secondary education(ref)	1	
Tertiary education	.841(.462-1.531)	0.573

Occupation

AI researcher(ref)	1	
Software developer	1.066(.208-5.444)	0.938
Computer engineer	.4(.091-1.749)	0.224
Data scientist	.8(.149-4.285)	0.794
Human right activist	2.8(.482-16.246)	0.251
Law student	.436(.143-1.323)	0.143
Lawyer	.177(.039-.805)	0.025***
Student	.371(.134-1.029)	0.057
University Lecturer	.218(.072-.660)	0.007***

***. $p<0.05$; (Field Data, 2024)

4.4 Presentation of qualitative findings

The narratives from the qualitative aspect of the study are presented to provide a thorough understanding of stakeholder perceptions, ethical implications and regulatory needs of AI. The themes that emerged reflect the ethical implications of AI, challenges in responsible AI use and regulation of AI. The themes are reinforcing and complementary to the quantitative aspect of the study while also highlighting a unique understanding of stakeholder perceptions, ethical implications and regulatory needs of AI.

4.4.1 Ethical implications of AI

Diverse ethical implications of AI were mentioned by stakeholders which included, accountability and transparency, fairness and bias in AI, privacy and data security and use of AI for harmful behaviour. The findings provide an understanding of ethical implications among stakeholders.

4.4.2 Accountability and transparency

Stakeholders demonstrated their understanding of the ethical implications of AI and the one major ethical implication mentioned was accountability and transparency of AI applications. For instance, one stakeholder said:

“The other things will be transparency and accountability to be considered. Now, you have to be transparent about how you correlate and create your data, they are ethical processes that you have to follow, using those ones being fair and open to people who you are actually taking their data, so that they know how you use it.”

Manager – AI startup

4.4.3 Fairness and bias in AI

An ethical implication that was also raised by stakeholders is fairness and bias in AI. Stakeholders explained how the biases of AI stem from AI algorithms.

A stakeholder stated that:

“So in using AI, Um, one of the things I would look at would be algorithm biases. And I mean how some of these algorithms are created. Let me give you a typical example. So I had the opportunity to attend the conference that was looking at a prediction of household. Um, well of females, and it turns out that the AI to be developed had some form of bias, so it set out to not include the females. The reason is that the data that was gathered right from onset in itself, was biased.”

Manager – AI startup

4.4.4 Privacy and data protection

Stakeholders discussed how AI can have a negative effect on the privacy of its users. The responses are presented below:

“The second thing will be something that has to do with privacy, AI solve problems but before they will be able to do all this someone has to train the model, depending on the kind of data you are going to train your model, your model will perform likewise. You may need data to train your model but the kind of data should actually protect the person who’s data you’re using like a research”

– AI Researcher

4.4.5 Use of AI for harmful behaviour

Stakeholders highlighted how AI could be misused to facilitate unethical behaviour, including fraud and invasion of privacy. A stakeholder said:

“Honesty, transparency, integrity we need these as social values. People are beginning to be corrupt to cheat the system and to defraud others, I don’t know whether AI will not actually promote this kind of activities, can AI look at people naked, that it lets some other people sit there and observe some other people naked because its artificial intelligence.”

– Lecturer

The findings reveal that stakeholders are aware of the ethical implications of AI and the need for responsible use.

4.5 Challenges in responsible AI use

Building on the ethical implications of AI, challenges were raised to include challenges with data, inclusive AI design, lack of regulations, misuse of AI and technical challenges.

4.5.1 Challenges with data

Stakeholders raised issues of challenges with data in the development of AI. Stakeholders indicated that data used to train AI models can't just be fetched anywhere and used to train the AI, rather, data should follow some ethical guidelines. A stakeholder reported:

"AI is a data driven something, basically you can't do AI without data because data is the key thing, it's just like the blood running through your veins because without it you can't survive and without data I will say that there is no AI because AI you need to train it on data for it to learn the patterns and everything for it to execute the purpose you want, you can't just go to anyplace, fetch data and come and feed it. You need to also take a look at the ethics in handling the data because the data is collected from a group of people."

– Computer Engineer

4.5.2 Lack of regulations

Concerns were also raised about the lack of AI regulations as a challenge of the responsible use of AI. A stakeholder stated:

"Number one will be supervision. So who can monitor it's use, number two in Ghana even when you make laws, implementing them becomes another problem. So for these two how to regulate or monitor it's use so that people do not abuse it and even when there is a regulation how to enforce it might be a challenge."

– Lecturer

4.5.3 Technical challenges

Stakeholders raised technical limitations of using AI in terms of infrastructure and local expertise. This is how a stakeholder puts it:

"Practically challenges is that it involves a lot of investment and then since AI has a tendency to affect human employment, it's emergence in that context makes AI merging into the main stream it makes it a bit challenging"

- Ministry of Justice Office, Copyright

4.5.4 Regulation of AI

Stakeholders expressed a strong need for regulations governing AI, particularly in the context of education, accountability, legal frameworks, and government policies. The responses demonstrate that effective regulation is critical to ensuring the responsible use of AI.

4.6 Education on AI

Stakeholders noted that effective AI regulation requires education and knowledge on AI among key legal and regulatory institutions. A stakeholder said:

“I think in order to effectively regulate AI, then it means people in the legal service must be knowledgeable in it. Not just the legal service but the whole institution of the correctional or criminal justice system. You see lawyers, how confessant are they with AI because they are the ones who will interpret the law, police, how confessant are they with AI.”

– Lecturer

4.7 Ensuring accountability

Stakeholders stressed the need for accountability within AI systems, advocating for regulations that hold developers and users responsible for the actions of AI. A stakeholder stated:

“For regulations, we have to look at accountability, AI should be accountable. People should be held accountable for the messes AI system creates, if an AI agent causes harm we should get someone we can attribute the blame to and that should be regulation itself, if you develop a bot today and it causes harm we should be able to tract it. You see it is very trivial because the developer can say it is the one who is using the bot or the data, you get it, but there must be accountability. For me I believe there must be a shared responsibility.”

– AI Researcher

4.8 Need for legal frameworks

Several respondents emphasized the importance of having legal frameworks that regulate the development and deployment of AI. These frameworks would serve as a check on AI systems before they are made available to the public, ensuring that they comply with ethical standards. Respondents had this to say about the need for legal frameworks:

“The first way I will talk about is regulation, ensuring that before it comes out it is being checked because someone will sit at their own comfort and just create something and drop it but if there is a system that checks out these models, AI apps. The system will ensure that... it’s just like the food and drugs authority. They ensure that what you

are bringing out is correct and according to the things you listed which are the exacts of the product.”

-AI Researcher

5. Discussion

The study examined stakeholder perceptions, predictors of trust, ethical implications and regulatory needs of AI in selected districts and municipalities in the greater Kumasi area. Stakeholders perceive AI positively due to its ability to increase efficiency and reduce cost, a finding consistent with Rane et al. (2024). Similarly, the integration of AI into daily life makes life easier, contributing to a positive view among users of AI (Islom, 2022). The challenges raised on the responsible use of AI, including job displacement, privacy and data issues, bias and fairness, are not unique to Ghana, but consistent with studies by Lui et al. (2023). These challenges underscore the need for Ghanaian policymakers to proactively address AI's social implications through robust data protection and fair employment transitions.

Participants revealed that they were neutral in their trust in AI in making decisions. This can be attributed to the several challenges and benefits attributed to AI. On the ethical concerns of adopting AI, several concerns, including lack of transparency in decision-making, privacy and data risks and potential bias in AI algorithms were raised. These concerns are consistent with global discussions on AI where transparency, fairness and privacy are identified as some of the most pressing ethical issues (Neha et al., 2023). Stakeholders believed that AI should be regulated to ensure its ethical use. The responses demonstrated that effective regulation is critical to ensuring responsible and ethical use. This clarion call for regulation is in line with global discussions, where scholars and practitioners alike argue for comprehensive regulatory frameworks to govern AI technologies, ensuring accountability, fairness, and transparency (Ryan, 2023). Further, the qualitative analysis also revealed that despite the need for regulation, there is a need to engage in public education on AI to ensure that individuals understand the ethical and responsible use of AI in order to use AI properly. Given the absence of a national AI policy in Ghana, the findings suggest an urgent need for Ghana to adopt sector-specific regulatory measures grounded in the local context.

The binary regression analysis shows that occupation is a significant predictor of trust in AI at the crude level, with lawyers, students, and university lecturers having significantly higher odds of trusting AI-powered applications compared to other occupations. In the same way, Li et al. (2024) in their study reported that trust in AI is influenced by several factors, including occupational background characteristics, resulting in different levels of trust in AI. The higher trust in AI by legal professionals,

students and university lecturers may be due to their exposure to structured decision-making processes where AI is already integrated, such as legal analytics and academic research. Interestingly, AI experts have high technical proficiency in AI since it is developed by them, however, variations in trust among them may be due to ethical concerns and unintended consequences in AI systems. This aligns with studies by Jarosław Kozak & Fel, (2024), who indicated that trust in AI is not solely dependent on expertise but also on perceived risk and ethical considerations.

6. Conclusion and Further Research

This study examined stakeholder perceptions, predictors of trust, and ethical implications of AI in Ghana, addressing a critical gap in localized AI studies. Findings reveal that while most stakeholders view AI positively, trust varies by occupation (e.g., lawyers and lecturers show higher trust), and ethical concerns center on transparency and data security. The overwhelming demand for regulation underscores the urgency for Ghana to develop inclusive, sector-specific frameworks that align with socio-cultural values. Future research should expand geographically to validate these findings. Policymakers can leverage these insights to prioritize accountability mechanisms and public education, ensuring AI aligns with Ghana's developmental goals.

References

- Floridi, L., Cows, J., Beltrametti, M., Chatila, R., Chazerand, P., Dignum, V., Luetge, C., Madelin, R., Pagallo, U., Rossi, F. and Schafer, B. (2018) 'AI4People—An Ethical Framework for a Good AI Society: Opportunities, Risks, Principles, and Recommendations', *Minds and Machines*, 28(4), pp. 689–707.
- Gwagwa, A., Kraemer-Mbula, E., Rizk, N., Rutenberg, I. and De Beer, J. (2020) 'Artificial intelligence (AI) deployments in Africa: benefits, challenges and policy dimensions', *The African Journal of Information and Communication*, 26, pp. 1–28.
- Hatem, N.A., Ibrahim, M.I.M. and Yousuf, S.A. (2024) 'Yemeni university students public perceptions toward the use of artificial intelligence in healthcare: A cross-sectional study', *medRxiv*, pp. 2024–02.
- Hoff, K.A. and Bashir, M. (2015) 'Trust in Automation: Integrating Empirical Evidence on Factors That Influence Trust', *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 57(3), pp. 407–434.
- Huang, M.-H. and Rust, R.T. (2018) 'Artificial Intelligence in Service', *Journal of Service Research*, 21(2), pp. 155–172.
- INSTITUTE OF ICT PROFESSIONALS GHANA - IIPGH - Barriers to Artificial Intelligence Adoption in Ghana' (2020) INSTITUTE OF ICT PROFESSIONALS GHANA, 21 August. Available at: <https://iipgh.org/barriers-to-artificial-intelligence-adoption-in-ghana/>
- Isom, P. (2022) 'Earning citizen confidence through a comprehensive approach to responsible and trustworthy AI stewardship and governance', *Journal of AI, Robotics & Workplace Automation*, 1(3), pp. 278–284.
- Kozak, Jarosław and Fel, S. (2024) 'How sociodemographic factors relate to trust in artificial intelligence among students in Poland and the United Kingdom', *Scientific Reports*, 14(1), p. 28776.
- Mhlambi, S. and Jahnke, A. (2021) 'Can an ancient African philosophy save us from AI bias', *Boston University, BU today*, 11.
- Novozhilova, E. et al. (2024) 'More Capable, Less Benevolent: Trust Perceptions of AI Systems across Societal Contexts', *Machine Learning and Knowledge Extraction*, 6(1), pp. 342–366.

Rane, N., Choudhary, S.P. and Rane, J. (2024) 'Acceptance of artificial intelligence: key factors, challenges, and implementation strategies', *Journal of Applied Artificial Intelligence*, 5(2), pp. 50–70.

Regional and International AI Regulations and Laws in 2024 (2024) Keymakr. Available at: <https://keymakr.com/blog/regional-and-international-ai-regulations-and-laws-in-2024/>

Ryan, M. (2023) 'The social and ethical impacts of artificial intelligence in agriculture: mapping the agricultural AI literature', *AI & SOCIETY*, 38(6), pp. 2473–2485.

Bridging The Digital Skills Gap In Ghana's Construction Industry Through Technical Vocational Education

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ABSTRACT:

Technical and Vocational Education and Training (TVET) plays a pivotal role in equipping skilled labour for the construction industry. As the construction industry faces a growing skills gap, Electronic Technical and Vocational Education and Training (E-TVET) offers new opportunities to enhance training demands. This research investigates the transformative potential of incorporating Virtual Reality (VR) and Artificial Intelligence (AI) in Technical and Vocational Education and Training (TVET), with a focused case study on Ghanaian institutions. The study demonstrates that immersive VR simulations in construction fields enable safe, cost-effective, and realistic hands-on training. At the same time, AI-driven adaptive learning personalizes instruction, aligns curricula with construction industry 4.0 demands, and provides real-time performance feedback. Employing a qualitative method approach, the research evaluates how this integration enhances skill acquisition, instructional quality, and workforce readiness in resource-constrained settings. Findings reveal that VR mitigates challenges such as limited access to equipment and safety risks, while AI optimizes adaptive assessments, reduces administrative burdens, and supports competency-based education. The Ghanaian case study further highlights improved learner engagement, higher certification rates, and stronger alignment with labour market needs. Grounded in constructivist learning theory and cognitive load theory, the study underscores the pedagogical efficacy of VR-AI systems in TVET, advocating for scalable adoption through policy frameworks and stakeholder collaboration. This research contributes to educational technology discourse by validating VR-AI as a sustainable model for future-ready workforce development, particularly in emerging economies.

KEYWORDS: Virtual Reality, Artificial Intelligence, TVET, immersive learning, adaptive training, Industry 4.0, competency-based education.

1. Introduction

The construction industry is one of the most profitable industries in the world. The industry is a determining driver of economic development and a cornerstone for national infrastructure, playing an essential role in gross domestic product (GDP) growth, employment creation, and social progress. This sector is particularly significant in developing economies, where it contributes up to 14% of GDP, serving as a catalyst for economic resilience and wealth creation through infrastructure investments (Cherian, 2020; Serogina et al., 2022; Lopes & Banaitienė, 2024). By facilitating the development of essential systems such as transportation, energy, and public utilities, construction underpins broader economic activities and addresses national economic and social objectives (Cherian, 2020; Serogina et al., 2022).

In recent times, the construction industry is undergoing a dramatic transformation because of technological advancement powered by the fourth industrial revolution (Industry 4.0). This revolution is gradually converting the sector into a digitalized system currently termed Construction 4.0. Construction 4.0 involves the introduction of new technologies designed to improve project performance in terms of reduction in construction cost, time and better quality (Osunsanmi et al., 2018; You & Feng, 2020; Sawhney et al., 2020; García de Soto et al., 2022). This shows a huge potential for the industry towards improving its productivity and sustainability. Ultimately, this will enhance the economic development of any nation that embraces this innovation. Similarly, this imminent development becomes essential for developing countries such as Ghana, more so, innovation and technological transformation are the key drivers of economic growth in developing countries (Onuogu et al., 2017).

2. Literature Review

2.1 Adaptation of TVET to provide future skills for future jobs

Many existing studies identify the jobs and skills most likely to be replaced by machines. However, history suggests this is not a predictable linear development (Mindell & Reynolds, 2023). For example, the advances in natural language processing and self-driving cars of the last decade were due to leaps in technology rather than to incremental advances. Hence, policy work on future skills required a tri-pronged approach involving:

- Anticipation of skill needs, as well as areas of deskilling, by surveying emerging technology
- Teaching of transversal or generic skills, particularly learning-to-learn skills, which would allow people to adapt to future changes in the labour market

through continued and lifelong learning

- Improving the responsiveness of educational systems to emerging trends, which requires close cooperation between education, research and industry to allow TVET systems to provide skills training in emerging areas.

At an extremely high level of abstraction, it is suggested that skills and jobs involving creative endeavours and social interactions are the most likely to show the highest resilience to change in the coming years (Grech & Camilleri, 2020). Also another study emphasizes the need for a strong emphasis on digital skills at every level of TVET (Roll, 2021), to facilitate adaptation to workplaces where manual tasks are being taken over by digital tasks and servicing digital workplaces, in terms of programming and engineering-related skills.

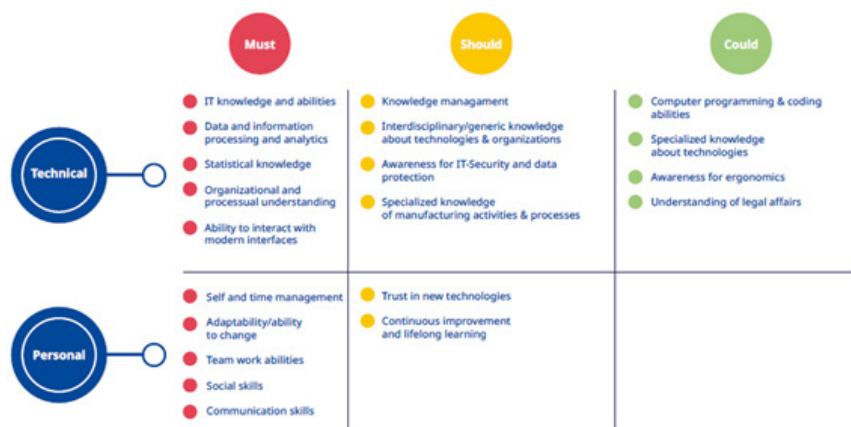


Figure 2. 1 Future qualifications and skills required from TVET (source: Gehrke et al., 2015)

2.2 Trends in digital education

2.2.1 Technologies driving digital innovation

It has been noticed in recent times that five technologies in particular are driving innovation in TVET, listed in the figure below.

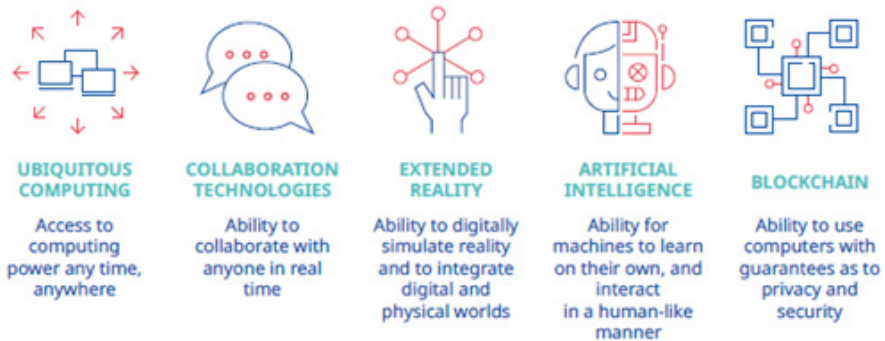


Figure 2. 2 Five technologies driving transformation in TVET (source: Grech & Camilleri, 2017)

2.2.2 Ubiquitous computing

Ubiquitous computing describes the technologies that give people access to information and computing power through the worldwide web from practically any place in the world. In a learning context, ubiquitous computing infrastructure is a pre-requisite for most applications of digital learning: in places with poor educational infrastructure, it can often be a pre-requisite for delivering any educational or training opportunities (Grech & Camilleri, 2020). Ubiquitous computing is associated with three technologies:

- Broadband describes high-speed internet, typically fast enough to support applications such as videoconferencing and remote control of equipment. Broadband was traditionally delivered to devices through cable and fibre connections, which require massive investments in infrastructure, since they need to be physically passed to each device (Briglauer et al., 2024).
- Mobile broadband describes technologies such as 3G, 4G and 5G, each allowing the wireless delivery of broadband to computing devices through radio

waves. Each of these technologies still requires the user to be within several hundred metres of a base station, which needs to be connected to a wired network. An innovation in this area is low-cost global satellite internet, which should allow anyone on Earth access to a mobile broadband connection with only a compatible router (Alimi et al., 2021).

- Cloud computing describes the offloading of computing tasks from a local device to a computer hosted in a data centre. Such tasks can involve anything from storing photos to processing large data sets. In each case, cloud computing allows a user to use a small, relatively low-powered device, while at the same time having access to the computing power of hundreds or even thousands of machines. Cloud computing depends on broadband to communicate between the local and remote devices (Wang et al., 2019).

Taken together, these technologies allow individuals to have access to practically unlimited information and computing resources, even from low-cost devices such as mobile phones, from anywhere in the world.

2.2.3 Collaboration technologies

Collaboration is the organization of joint efforts among actors to achieve a shared goal. It is a perennial and integral part of human life, given that we are social beings. However, modern life has increased both the necessity for and complexity of collaboration, bringing about complex production and political systems that require highly coordinated efforts to function (Grech & Camilleri, 2020).

The digital age, driven by the advent of network computing, the internet and mobile devices, has added an entirely new layer of both opportunity and challenges. The ability to communicate, exchange information, and collaborate across space and time has given us new forms of working, new types of (virtual) organization and the reconfiguration of markets (Grech & Camilleri, 2020). This, in turn, has spurred innovation across different sectors of the economy, enabling heretofore impossible collaboration across national and disciplinary boundaries. Yet all of this comes at a cost. Collaboration online without face-to-face contact is not frictionless; it requires new skills and hidden 'collaboration work', above and beyond the 'actual work'. New, multi-stakeholder, networked forms of organizing come with new coordination costs, sources of conflict and the need to renegotiate the fair distribution of value.

Grech and Camilleri (2020) emphasize that, many technologies with a 'social' element incorporated in the software would qualify as collaboration technologies. Social networks such as Facebook and Google Groups can facilitate collaboration; the same can be said for Dropbox, Google Drive, WhatsApp and Skype. Collaboration tools in 2019 are primarily associated with work efficiency and project tracking, and the integration of a number of tools into one interface. For instance, Slack3 is a smart platform that works on mobile and desktop devices, and allows sending direct messages and files to a single person or a group of employees. Slack also has the ability to organize conversations into different channels (specific projects, general chat, etc.) The app supports video calling, and drag, drop and sharing of files with colleagues directly within Slack. It is also compatible with services such as Google Drive, Dropbox and Box indicated by Grech and Camilleri (2020).

2.2.4 Extended reality technologies

Extended reality technologies variously incorporate a range of different technologies, including (Dixon et al., 2022):

- Virtual reality, (VR) is the most widely known of these technologies. It is fully immersive, tricking the senses into thinking one is in a different environment or world outside of the real world. Using a head-mounted display or headset allows the user to experience a computer-generated world of imagery and sounds, manipulating objects and moving around using haptic controllers while tethered to a console or PC (Al-Ansi et al., 2023). For example, VR allows 'visits' to 3D-simulated workplaces.
- Augmented reality, (AR) overlays digital information on real-world elements, either through a headset or a mobile device such as a phone. AR keeps the real world as a central construct, but enhances it with other digital details, layering new strata of perception and supplementing an individual's reality or environment (Dargan et al., 2023). In education, for example, an AR headset could be used to overlay educational instructions onto production equipment, indicating indicate precisely which button to press, which screw to unscrew, etc. in a live environment
- Mixed reality, (MR) brings together real-world and digital elements. It allows interacting with and manipulate both physical and virtual items and environments, using next-generation sensing and imaging technologies. MR allows people to see and immerse themselves in the world around them even as they interact with a virtual environment using their own hands (Morimoto et

al., 2022). Examples of MR include dedicated simulators, such as those used in aerospace.

These terms cover a set of methodologies whereby students can control software and systems remotely. These may include:

- i. Shared remote control of equipment: a single model of an expensive piece of equipment is located within a lab or work context, and students from different locations can log on and use it for specific periods of time (Heradio et al., 2016). Examples of such a setup might include shared custody of a 3D printer or shared use of computer resources in a cloud.
- ii. Simulations of industrial control systems: students can 'operate' industrial machines by using the same software that is used by the machines, but is connected to virtual machines (Vergnano et al., 2017). Examples include anything from flight simulators to control systems for factory production lines.

2.2.5 Artificial intelligence

AI is a group of technologies and techniques, notably those linked to deep learning, natural language processing and signal recognition, which allow computers to learn and interact similarly to humans (Deng and Li, 2018).

The computer would not need to be given rules to determine what constitutes a cat thus, the mere act of giving it thousands of labelled images would allow it to deduce these rules on its own (Deng and Li, 2018).

We imagine that the most immediate applications of AI to TVET would therefore involve the following items:

i. Natural language processing

This is a subfield of deep learning, i.e. the ability to train computers based on large data sets. Using large data sets of typical standardized conversations (for example, students asking questions linked to a topic), translations or conversations, computers are increasingly able to simulate and understand natural speech, accept natural speech as an input to queries and even translate text between languages.

Natural language processing has a broad range of applications within education (Shaik et al., 2022), including:

Recommender systems

Recommender systems use massive data sets of user preferences to intuit what users might need (Deng & Li, 2018).

In a TVET system built out of hundreds of distinct units, AI could be used to recommend (a) educational/ training resources; (b) learning opportunities; and (c) personalized career pathways, based on aptitude, educational goals and past performance.

2.2.6 AI for teaching and assessment

An extension of the two capabilities described above consists in using AI programmes to teach material by presenting content to each student in a different way, based on the student's learning preferences, as well as to grade assessments.

While both applications exist, they suffer from a lack of sufficient training material to adequately train sophisticated AI (Liang et al., 2022). Therefore, most applications have been used to assess standardized tests applied to large volumes of students.

2.2.6.1 Blockchain

Blockchain, more formally known as distributed ledger technologies, is predicted to offer significant opportunities to disrupt traditional products and services thanks to the distributed, decentralized nature of blockchains, features such as the permanence of the blockchain record, and the ability to run smart contracts. These features significantly distinguish blockchain technology-based products or services from previous internet-based commercial developments. They are of particular interest to the education sector although education, with some minor exceptions, is not currently perceived as high on the agenda of countries with national blockchain initiatives (Grech & Camilleri, 2020).

Blockchain technology is forecast to disrupt any field of activity that is founded on time-stamped ledgers. Within education, activities that could be impacted by blockchain technology include certification, management of student records, intellectual property management, issuing of payments and student information system architecture.

From a social perspective, blockchain technology allows (Grech & Camilleri, 2020):

- self-sovereignty, thus users can maintain direct control over the storage and management of their personal data
- trust, i.e. the technical infrastructure gives people enough confidence in its operations to carry through with transactions such as payments or the issuance of certificates
- transparency and provenance, thus users can conduct transactions with the

knowledge that each party has the capacity to enter into that transaction

- immutability, i.e. records can be written and stored permanently, without the possibility of modification
- disintermediation, thus there is no more need for a central controlling authority to manage transactions or keep records
- collaboration, thus parties have the ability to transact directly with each other, without the need for third parties

2.3 Adaptation and acceleration of TVET pedagogies to digitization

Learners can learn individually or collaboratively through a multitude of technology-enabled methodologies, including writing activities, game-like learning environments, simulations, and AR. The combination of school and work-based actors (teachers and supervisors) and actions (intertwining learning activities at both locations) is what makes TVET unique. However, current research and practice often neglects the possibilities of investigating the role of collaboration in vocational education, where the interaction between people in different locations is fundamental to the systems' effective functioning (Schwendimann et al., 2018).

Given these limitations, six areas of learning hold promise for TVET: distance learning and assessment, simulation, flipped classrooms, gamification, open education (resources) and personalization. Figure 2.3 provides a brief description of each.

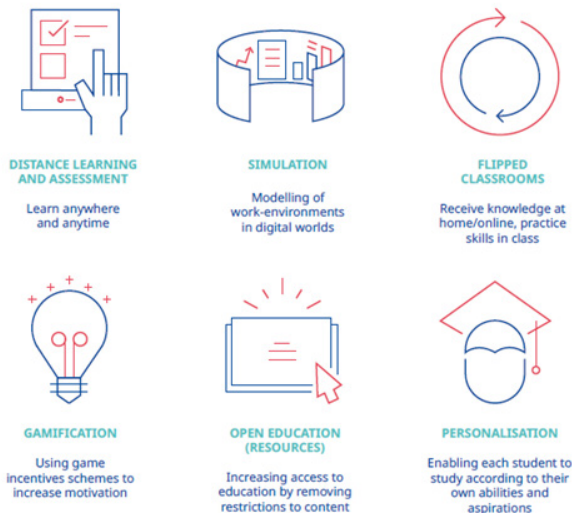


Figure 2. 3 Six areas of learning holding promise for TVET (source: Grech & Camilleri, 2017)

2.3.1 Distance learning and assessment

Distance learning (or distance education, also open and distance learning [ODL]) is a field of education that focuses on the pedagogy, technology and instructional systems design that deliver education to students who are not physically 'on-site'. Distance learning is the process of creating an equally qualitative educational experience that best suits the needs of learners outside the classroom. Rather than attending courses in person, teachers and students may communicate at times of their own choosing by exchanging printed or electronic media, or they may use technology that allows them to communicate in real time. Distance education courses that require a physical on-site presence for any reason, including for taking examinations, is considered a hybrid or blended course of study. Massive Open Online Courses (MOOCs) are considered part of distance learning (McAuley et al., 2010).

The main strength of distance learning is that it allows students who are not able to participate in a classroom at a fixed place and at fixed times to still follow courses. This is strongly linked to improving student equity through improved opportunities to learn. Figure 2.4 shows the evolution of learning technologies from self-study and passive learning to collaborative and experiential learning (McAuley et al., 2010).

MOOCs have received significant attention as an evolution of distance learning. McAuley et al. (2010) define a MOOC as a class that integrates the connectivity of social networking, the facilitation of an acknowledged expert in a specific field of a study and a freely accessible course, designed be offered at scale through the internet.

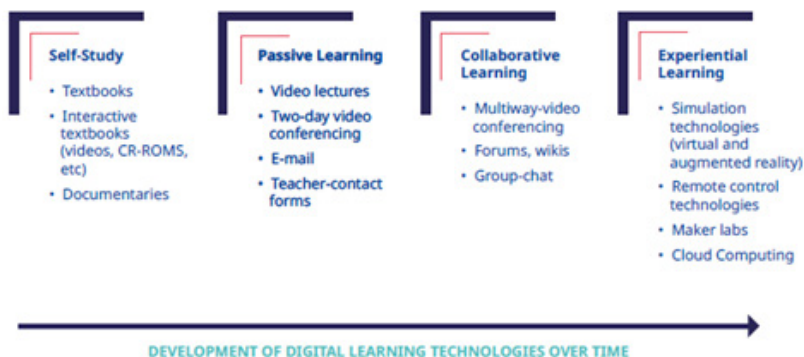


Figure 2. 4 Evolution to digital learning technologies (source: Grech & Camilleri, 2017)

The acronym ‘MOOC’ refers to its main characteristics, as follows:
Massive, it sets theoretically no limits to enrolment.
Open, it allows anyone to participate, usually at no cost.
Online, learning activities typically taking place over the web.
Course, it is structured around a set of learning goals in a defined study area.

MOOCs have been traditionally classified as xMOOCs and cMOOCs: xMOOCs resemble a ‘traditional’ course, with predefined learning outcomes for learners, syllabi and structured OERs – or to some extent also proprietary material – as well as homework and assessment; cMOOCs emerged as examples of connectivism, where learning is distributed, social and explorative (Grech & Camilleri, 2020). As the market develops, MOOCs are finding a niche in the provision of microlearning through distance learning at scale (Figure 11).

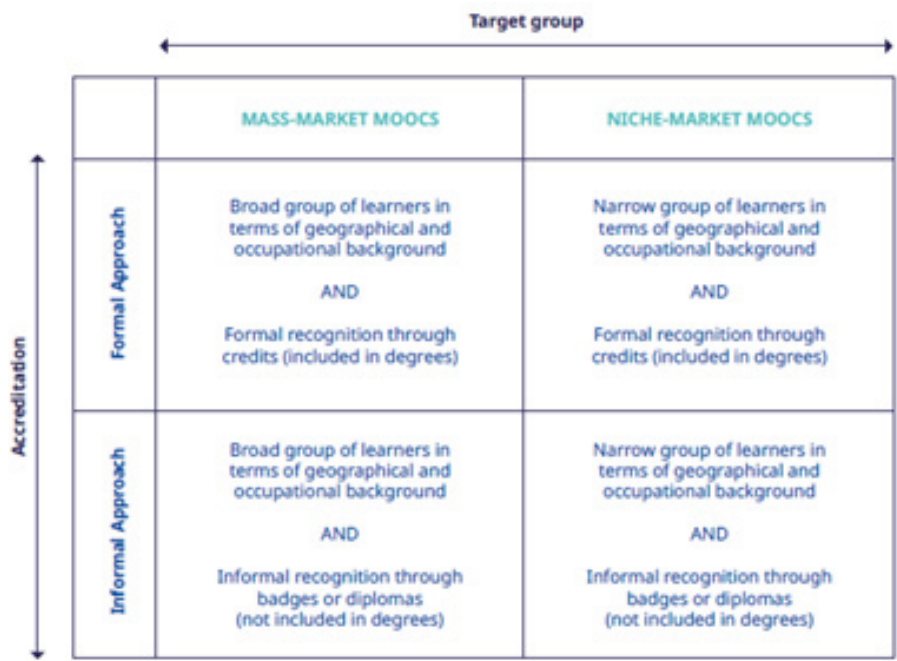


Figure 2. 5 MOOC typology framework (source: Dalipi et al., 2018)

The current wave of technological development focuses on commoditizing the technologies for experiential learning, making technology that used to cost millions of dollars available for amounts in the hundreds or low thousands. This is leading to the next frontier in the evolution of distance learning, whereby practical skills can be taught remotely (Schlimbach et al., 2023).

Distance assessment is also increasingly complementing distance learning through a mixture of technologies, including: (a) use of technology to detect plagiarized texts in long-form assignments, (b) remote proctoring to allow students to take examinations from home, (c) identification technologies using biometric signature.

2.3.2 Simulation

By allowing trainees to learn and make mistakes in a realistic yet risk-free environment; providing memorable, immersive experiences that evoke emotion; and overcoming the practical barriers associated with traditional education, VR is beginning to prove its worth as a valuable training tool. VR-based training removes the costs of traditional training, such as venue hire, travel, consultant fees or simply time spent away from work. Sessions can be delivered remotely by mentors or through software housed within a shared platform (Scorgie et al., 2024). VR-based training is more engaging than listening to a talk, reading a manual or watching a video demonstration. Trainees who can explore virtual environments with their own eyes and (digital) hands are less likely to get bored and have a better chance of retaining what they have learned. Memory recall with immersive VR training can be up to 300 per cent higher than with traditional training (Scorgie et al., 2024).

For instance, Tyson Foods uses VR to train employees to safely use complex machinery, allowing them to practise and learn at their own pace before they even enter the company's physical plant (Tyson, 2018). The technology also helps overcome other barriers associated with traditional training.

2.3.3 Flipped classrooms

Flipped classrooms were originally invented for a high school chemistry class in Colorado (Bergmann & Sams, 2009). The Flipped Learning Network defines it as a pedagogical approach whereby direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter.

Figure 2.6 shows an example of a typical flipped classroom approach, adapted from the University of Adelaide.

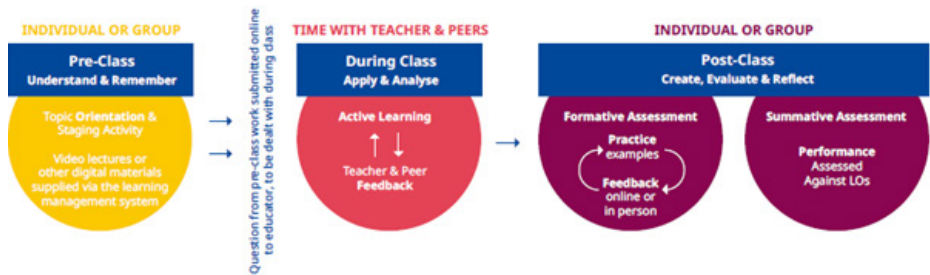


Figure 2. 6 Elements of a flipped classroom approach adapted from University of Adelaide

Statistics on the use of flipped classrooms in TVET are hard to come by, although studies from China show widespread use in the country. One meta-study of nursing schools was able to identify twenty-nine academically reviewed reports of nursing schools across China using the technique, concluding that it helps nursing students improve in knowledge, skills, self-learning, study satisfaction and enthusiasm (Tan et al., 2017).

2.3.4 Gamification

Gamification is defined as the introduction or application of elements of games to non-game contexts. It is a relatively new concept, but an old practice. Games and the elements that make up games have been incorporated into other areas of life throughout history. This is particularly true of education, where the need to ensure student interest and participation has meant that game mechanics such as rewards and group tasks have become core teaching tools (Wang & Huang , 2021).

According to the World Government Summit, all games share three fundamental characteristics (Oxford Analytica, 2016): (a) clearly defined set of rules, (b) rapid feedback system, (c) a well-established goal

With few exceptions, participation in games is voluntary and primarily for enjoyment. Among the many elements comprising games, the three of particular relevance to education are: (a) mechanical elements, such as incremental progression, onboarding and instant feedback, (b) personal elements, such as status and visibility, collective responsibility and leader boards or rankings, (c) emotional elements, particularly the psychological state of flow. While gamification is well embedded in tertiary education, gamification in TVET is not a well-researched area (Surendeleg et al., 2014). Our literature review was also only able to generate a handful of papers in this area. That said, it is possible to make some assumptions on its use, in

that all major learning management systems and MOOC platforms contain significant implementations of gamification.

2.3.5 Open educational resources

Open provision of these course materials has become more widespread, particularly thanks to MOOCs, and many institutions have adopted this approach. This might be described as concluding the first phase of OER development and diffusion, which focuses on access to and the availability of OER. Phase 2 is currently emerging in the debate, literature and policy discourse. This phase is about using OER in a way that improves learning experiences and generates innovation in educational scenarios. This next phase in OER development will shift from focusing on resources to focusing on open educational practices (Camilleri et al., 2014).

Aside from open educational practices, open education has also come to encompass (Hodgkinson Williams & Gray, 2009): (a) Social openness, the degree to which pedagogy is didactic or participative, through sharing, collaboration, participation and contribution. This might be enabled through tools such as constructivist MOOCs. (b) Technical openness: the degree to which software/platforms on which OER are based are themselves open or closed source. The best-known example here is MediaWiki, which is fully open-sourced by the Wikipedia Foundation. (c) Financial openness: the use of financial models that enable the widest access to the largest number of students. This might include offering free education, sponsored education, vouchers, pay-as-you-go systems and other innovative financial models.

2.3.6 Personalization

The last century of education policy might be termed the 'massification of education', whereby education grew from a niche pursuit for the well-off and the elites into a basic commodity, provided as a human right for all. Within the context of a Fordist economic paradigm, education for all meant mirroring and reflecting the efficiencies of the predominant industrial model, providing the same education in the same manner at low cost and at scale to masses of students. Educational literature has long indicated that different students learn in different ways and that a more personalized approach, with learning customized to the learning needs of each student, would bring about greater individual benefits. However, until now, it has been impossible to scale such techniques for an affordable cost. Personalized learning can be looked at through a variety of lenses (Järvelä, 2006):

- Use of technology: technology can be used to automate any task that is repeatable – particularly information delivery and standardized assessment. Doing so radically lowers the cost of these processes and allows delivering different information to different students according to their needs and preferences.
- Levelling the educational playing field through guidance for improving students' learning skills and motivation: in a personalized learning environment, students' preference to follow a vocational or academic career is determined based on their needs and aspirations.
- Encouraging learning through a 'motivational scaffolding': this uses technological tools to help students envisage the careers they would like to follow, and then suggest a personalized learning pathway comprising relevant theoretical and practical components to reach this goal.
- Development of domain-specific key skills: rather than a standardized curriculum for all students, all students receives training in the vocational skillset for which they have shown propensity.
- Collaboration in knowledge building: rather than merely 'consuming' information, students are active constructors of their own knowledge, often through collaboration with peers.
- Teachers' new role in better integrating education within the learning society: with technology freeing teachers from the task of information delivery, they can take on a new role as guides to help students identify and travel along their chosen personalized pathways.
- Freedom to determine time and place of learning: students get far greater choice about the mode, place and time of learning, thanks to technology allowing them to receive information and collaborate at any time, from nearly any location.

One of the largest expressions of personalization in TVET is microlearning which consists in mastering a limited set of skills or competencies rather than broader and interrelated sets of skills, like full qualifications.

Complementing students' participation in at-school programmes, microlearning allows students to participate in programmes outside of formal regulatory frameworks, which offer unaccredited certificates that do not count towards an award course. However, these micro-credentials and badges provide employers with a well-rounded picture of employee competencies, skills and other important veri-

fiable information. Consequently, Hurst (2015) proposes that digital badge use in workplace settings and in TVET may emerge as the most prominent area of adoption. Employers can use micro-credentials to overcome skills gaps within their workforce, as part of training programmes that better fit the needs and constraints of employees. Major companies are embracing micro-credentials for professional development, partnering with educational institutions. This trend is transforming TVET by giving learners more control over their education.

3. Conclusion

3.1 The affordances of digitalization require the TVET sector to become more proactive.

Only a handful of countries have developed a clear and unified approach to digitalizing their TVET and skills development systems. In terms of policy, most national strategies concentrate on digital transformation, often prioritizing:

- Updating TVET and skills training to include both technical and soft skills aligned with current labor market demands
- Enhancing students' readiness for employment
- To a lesser degree, fostering entrepreneurial abilities that enable learners to create or pursue their own job opportunities

The study found limited evidence of explicit macro-level strategies to increase efficiencies and impact of TVET through digitization, and has not mentioned it as a potential accelerator for social changes. Initiatives may be driven by institutions, industry, employment policy, or education ministries, complicating the formulation of high-level digital strategies.

3.2 Digital TVET is driving a positive transformation in the quality, quantity and type of apprenticeships

The rise of Industry 4.0 has significantly increased the reliance on software to operate hardware across all levels and sectors of the workforce. These software tools are often tailored or specifically designed for particular industries, making them unsuitable for one-size-fits-all training approaches.

Due to high costs associated with training students on these technologies outside the workplace, on-the-job learning methods like apprenticeships are becoming increasingly valuable.

In addition, technology is playing a key role in enhancing the management of apprenticeship programs by:

- Enabling easier discovery of opportunities through online matching platforms and apprenticeship job boards
- Supporting real-time tracking of placements via digital logbooks accessible to all relevant parties
- Facilitating the assessment of individual placements and broader programs through tools that allow performance benchmarking and alignment with specific training providers

3.3 The cost of digital delivery and assessment increases dramatically as the complexity and sophistication of the offering increase

Digital TVET is evolving to emphasize hands-on learning through simulation technologies, which range from basic skill training to advanced, specialized tasks. While these simulations are safer and more affordable than real workplace setups, they require significant investment in technology and skilled personnel. The lack of up-front funding is a major obstacle to their widespread adoption in many countries.

The responsibilities of educators are shifting, especially in the context of digital learning. While they still play a key role in developing materials for teaching basic skills, especially when using open educational resources (OER) that are affordable and adaptable, this is less the case for advanced skill simulations. In these instances, the creation of training tools often falls to the manufacturers of the actual systems. Educators then support learners by facilitating these manufacturer-designed simulations during apprenticeships.

3.4 Digital TVET reinforces the fundamentals of TVET as a three-party collaboration requiring the buy-in of policymakers

The success of digital TVET relies on strong collaboration among employers, educators, students, and policymakers. It necessitates co-designed learning experiences that reflect real work environments, swift responses to evolving skill demands, student-centered teaching, and ongoing industry exposure for educators. Modern digital tools facilitate this collaboration through real-time monitoring, on-line feedback, and virtual training environments.

4. Recommendations

Design programmes that enhance the evidence base informing transformation

(a) Commission studies for countries that are digitally and TVET-ready

This study reinforces the OECD's 2018 findings that countries differ greatly in how well-prepared they are to embrace the digital transformation of TVET, largely based on the skill levels of their adult populations. These differences are often rooted in deeply embedded socio-economic and cultural factors that resist change driven solely by technology.

To address this, a research was carried out by ILO and UNESCO. Based on their findings from the study, several key observations emerged:

Firstly, Ghana, Kenya, and New Zealand stood out as countries that showed strong readiness for both digital integration and advancement in TVET systems. These nations were demonstrated the foundational capacity and openness required to implement digital innovations in vocational education.

Secondly, programs aimed at addressing youth unemployment and supporting refugees appeared to be the most impactful areas for future investment in digital technology. These focus areas held significant potential for driving meaningful social change through improved access to skills and employment opportunities.

Lastly, several international organizations are well-positioned to support ongoing research and program development in this space. These include the UNHCR, the Mastercard Foundation—recognized for its previous work on digital credentials for unemployed individuals in Africa—the MIT Media Lab, and the Inter-American Development Bank (IDB), which continues to explore accreditation systems for online education focused on disadvantaged populations.

(b) Enact strategies for digital transformation

Effective digital transformation in TVET depends on problem-focused pilot programs and strong collaboration with industry. Malaysia's success demonstrates how data-driven apprenticeships and joint curriculum development can lead to scalable, sustainable outcomes. Sectors like agriculture, even in low-literacy contexts such as India, benefit from digital tools when supported by knowledgeable trainers.

Cultural norms significantly influence the success of digital adoption, requiring strategies that align with local values. Digital technologies also open the door to reforming traditional assessments, lowering educational costs and modernizing

learning delivery.

A key challenge remains the international recognition of TVET qualifications. Digital solutions can help establish systems for cross-border credential acceptance, particularly important for refugees and marginalized learners. Countries like Canada are already supporting these efforts with transitional certifications, but broader policy shifts and university partnerships are needed to create more inclusive learning pathways.

REFERENCE

Al-Ansi, A.M., Jaboob, M., Garad, A. and Al-Ansi, A., 2023. Analyzing augmented reality (AR) and virtual reality (VR) recent development in education. *Social Sciences & Humanities Open*, 8(1), p.100532.

Alimi, I.A., Patel, R.K., Muga, N.J., Pinto, A.N., Teixeira, A.L. and Monteiro, P.P., 2021. Towards enhanced mobile broadband communications: A tutorial on enabling technologies, design considerations, and prospects of 5G and beyond fixed wireless access networks. *Applied Sciences*, 11(21), p.10427.

Bergmann, J. and Sams, A. 2009. Remixing Chemistry Class: Two Colorado Teachers Make Vodcasts of Their Lectures to Free Up Class Time for Hands-On Activities. *Learning & Leading with Technology*, Vol. 36(4), pp. 22–27.

Briglauer, W., Krämer, J. and Palan, N., 2024. Socioeconomic benefits of high-speed broadband availability and service adoption: A survey. *Telecommunications Policy*, p.102808.

Byrnfjolfsson, E. and McAfee, A. (2014). *The Second Machine Age*. New York, NY: W. W. Norton & Company Inc.

Camilleri, A. F., U. Ehlers, and J. M. Pawlowski. 2014. State of the Art Review of Quality Issues related to Open Educational Resources (OER) (No. JRC88304; p. 56). Joint Research Centre – Institute for Prospective Technological Studies. <http://is.jrc.ec.europa.eu/pages/EAP/documents/201405JRC88304.pdf> (Accessed 08 June 2025).

Cherian, A. The construction industry in the perspective of an economic boost of the United Arab Emirates. *International Research Journal of Engineering and Technology (IRJET)* 2020, 07(08), pp. 270-276.

Dargan, S., Bansal, S., Kumar, M., Mittal, A. and Kumar, K., 2023. Augmented reality: A comprehensive review. *Archives of Computational Methods in Engineering*, 30(2), pp.1057-1080.

- Deng and L., 2018. Artificial intelligence in the rising wave of deep learning: The historical path and future outlook [perspectives]. *IEEE Signal Processing Magazine*, 35(1), pp.180-177.
- Dixon, E., Anderson, J. and Lazar, A., 2022. Understanding how sensory changes experienced by individuals with a range of age-related cognitive changes can affect technology use. *ACM Transactions on Accessible Computing (TACCESS)*, 15(2), pp.1-33.
- García de Soto, B., Agustí-Juan, I., Joss, S. and Hunhevicz, J., 2022. Implications of Construction 4.0 to the workforce and organizational structures. *International journal of construction management*, 22(2), pp.205-217.
- Gebhardt, J., Grimm, A. and Neugebauer, L. M. 2015. Developments 4.0 – Prospects on future
- Gehrke, L., A. Kühn, D. Rule, P. Moore, C. Bellmann, S. Siemens, D. Dawood, L. Singh, J. Kulik, and M. Standley 2015. A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective. Düsseldorf, Germany: The Association of German Engineers (VDI). https://www.researchgate.net/profile/Lars_Gehrke/publication/279201790_A_Discussion_of_Qualifications_and_Skills_in_the_Factory_of_the_Future_A_German_and_American_Perspective/links/558fcf1708ae47a3490db5e1/A-Discussionof-Qualifications-and-Skills-in-the-Factory-of-the-Future-A-German-and-American-Perspective.pdf (Accessed 12 June 2025).
- Grech, A. and Camilleri, A. F. 2017. Blockchain in Education. <https://ec.europa.eu/jrc/en/publication/eurscientific-and-technical-research-reports/blockchain-education> (Accessed 12 June 2025).
- Grech, A. and Camilleri, A.F., 2020. The digitization of TVET and skills systems.
- Heradio, R., de la Torre, L. and Dormido, S., 2016. Virtual and remote labs in control education: A survey. *Annual Reviews in Control*, 42, pp.1-10.
- Hodgkinson-Williams, C. and Gray, E. 2009. Degrees of openness: The emergence of open educational resources at the University of Cape Town. *International Journal of Education and Development Using ICT*, 5(5). <http://www.editlib.org/p/42198/> (Accessed 09 June 2025).
- Hurst, E. J. 2015. Digital Badges: Beyond Learning Incentives. *Journal of Electronic Resources in Medical Libraries*, 12(3), 182–189. <https://doi.org/10.1080/15424065.2015.1065661> (Accessed 08 June 2025).

- Järvelä, S. 2006. Personalised learning? New insights into fostering learning capacity. OCDECERI (eds), *Personalising Education*. Paris: OECD/CERI, pp. 31–46. <http://www.oecd.org/site/schoolingfortomorrowknowledgebase/themes/demand/41176687.pdf> (Accessed 07 June 2025).
- Liang, W., Tadesse, G.A., Ho, D., Fei-Fei, L., Zaharia, M., Zhang, C. and Zou, J., 2022. Advances, challenges and opportunities in creating data for trustworthy AI. *Nature Machine Intelligence*, 4(8), pp.669–677.
- Lopes, J.; Banaitienė, N. A model for construction sector development in middle-income sub-saharan African countries. *Technological and Economic Development of Economy* 2024, pp. 1–27.
- McAuley, A., B. Stewart, G. Siemens, and D. Cormier 2010. The MOOC model for digital practice. https://pdfs.semanticscholar.org/ad53/b9655587771edcf4ae028d4490a218d87ff2.pdf?_ga=2.201095853.2091277458.1585842495-481342936.1585670719 (Accessed 12 June 2025).
- Mindell, D.A. and Reynolds, E., 2023. *The work of the future: Building better jobs in an age of intelligent machines*. Mit Press.
- Morimoto, T., Kobayashi, T., Hirata, H., Otani, K., Sugimoto, M., Tsukamoto, M., Yoshihara, T., Ueno, M. and Mawatari, M., 2022. XR (extended reality: virtual reality, augmented reality, mixed reality) technology in spine medicine: status quo and quo vadis. *Journal of Clinical Medicine*, 11(2), p.470.
- Olanmi, E.E., 2017. The effects of a flipped classroom model of instruction on students' performance and attitudes towards chemistry. *Journal of Science Education and Technology*, 26, pp.127–137.
- Onuogu, I.C., Hassan, A., Akadiri, S.S., Bello, A.A. and Riti, J.S., 2024, October. Impacts of ICT diffusion, foreign direct investment, trade openness, and globalization on growth in Sub-Saharan Africa. In *Natural Resources Forum*. Oxford, UK: Blackwell Publishing Ltd.
- Osunsanmi, T. O, Aigbavboa, C., Oke, A., & Ohiomah, I. (2018). Towards delivery of sustainable houses in South Africa. *Proceedings of Creative Construction Conference*, Diamond Congress Ltd, Ljubljana, Slovenia, 30 June–July 3, 2018.
- Oxford Analytica. 2016. Gamification and the Future of Education. *World Government Summit 2016*. <https://www.worldgovernmentssummit.org/api/publications/document?id=2b0d6ac4-e97c-6578-b2f8-ff0000a7ddb6> (Accessed 08 June 2025).

requirements and impacts on work and vocational education. *Journal of Technical Education (JOTED)*, Vol. 3, pp. 117–133.

Roll, M., 2021. Development of multidisciplinary digital competencies to prepare technical vocational students for industry 4.0. *Universitaet Mannheim (Germany)*.

Sawhney, A., Riley, M., Irizarry, J. and Riley, M., 2020. *Construction 4.0*. Sawhney, A., Riley, M., Irizarry, J., Eds.

Schlimbach, R., Lange, T. and Robra-Bissantz, S., 2023. A Longitudinal Study on Boosting Students' Performance with a Learning Companion. In *International Conference on Information Systems, Hyderabad*.

Schwendimann, B. A., B. D. Wever, R. Hamalainen, and A. A. P. Cattaneo. 2018. The state-of-the-art of collaborative technologies for initial vocational education: A systematic literature review. *International Journal for Research in Vocational Education and Training (IJRVET)*, Vol. 5(1), pp. 19–41.

Scorgie, D., Feng, Z., Paes, D., Parisi, F., Yiu, T.W. and Lovreglio, R., 2024. Virtual reality for safety training: A systematic literature review and meta-analysis. *Safety science*, 171, p.106372.

Serogina, D.; Pushkar, T.; Zhovtiak, H. The impact of the construction industry on the social and economic development of territories. *Scientific Bulletin of the National Academy of Statistics, Accounting and Audit* 2022, pp. 1-7.

Shaik, T., Tao, X., Li, Y., Dann, C., McDonald, J., Redmond, P. and Galligan, L., 2022. A review of the trends and challenges in adopting natural language processing methods for education feedback analysis. *Ieee Access*, 10, pp.56720–56739.

Surendeleg, G. et al. 2014. The role of gamification in education-a literature review. *Contemporary Engineering Sciences*, Vol. 7(29), pp. 1609–1616.

Tan, C., Yue, W.G. and Fu, Y., 2017. Effectiveness of flipped classrooms in nursing education: Systematic review and meta-analysis. *Chinese Nursing Research*, 4(4), pp.192-200.

Tyson. 2018. Better safety through virtual reality: Looking to the future of workplace safety. <https://thefeed.blog/2018/10/23/better-reality-through-virtual-reality-looking-to-the-future-of-workplace-safety/> (Accessed 11 June 2025).

Vernano, A., Berselli, G. and Pellicciari, M., 2017. Interactive simulation-based-training tools for manufacturing systems operators: an industrial case study. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 11, pp.785-797.

Wang, C. and Huang, L., 2021. A Systematic Review of Serious Games for Collaborative Learning: Theoretical Framework, Game Mechanic and Efficiency Assessment. *International Journal of Emerging Technologies in Learning*, 16(6).

Wang, J., Pan, J., Esposito, F., Callyam, P., Yang, Z. and Mohapatra, P., 2019. Edge cloud offloading algorithms: Issues, methods, and perspectives. *ACM Computing Surveys (CSUR)*, 52(1), pp.1-23.

You, Z. and Feng, L., 2020. Integration of industry 4.0 related technologies in construction industry: a framework of cyber-physical system. *Ieee Access*, 8, pp.122908-122922.

The Role Of Generative AI In Built Environment Research: A Systematic Literature Review

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ABSTRACT:

The rapid advancement of artificial intelligence technologies has created unprecedented opportunities for transforming built environment research methodologies. This systematic literature review examines the current state, knowledge gaps, and future directions of generative AI applications across architecture, urban planning, construction management, and environmental design disciplines. Following the PRISMA framework, 21 peer-reviewed publications from Scopus and Web of Science databases (2022-2025) were analyzed through bibliometric and content analysis. The findings reveal that generative AI is fundamentally reshaping research practices through applications in design generation, multimodal data analysis, decision support systems, and educational transformation. Key research areas include aesthetic assessment using multimodal language models, digital twin development, automated knowledge extraction, and human-AI collaboration frameworks. However, significant gaps persist, including limited AI-human perception alignment, insufficient domain-specific model development, scalability constraints, and inadequate validation frameworks. The absence of longitudinal studies and comprehensive ethical guidelines further limits understanding of AI's long-term impacts. The study identifies eight strategic research directions: developing specialized AI models for built environment applications, establishing validation protocols, enhancing collaborative frameworks, creating interdisciplinary integration methods, transforming educational approaches, building ethical governance structures, developing scalable infrastructure, and conducting longitudinal impact assessments. Geographic analysis reveals research concentration in China, the United States, and the United Arab Emirates, indicating the need for broader global participation. This review provides researchers and practitioners with a comprehensive understanding of AI's transformative potential, especially in the built environment, while highlighting critical challenges requiring collaborative solutions from academic, industry, and regulatory stakeholders to ensure responsible and effective AI integration in built environment research.

KEYWORDS: Generative AI, Large Language Modules, Built Environment, Research Methodology, Systematic Literature Review, ChatGPT

1. Introduction

The built environment research domain is inherently complex, with methodologies that have remained largely static for decades across architecture, urban planning, construction management, and environmental design disciplines (Thampanichwat et al., 2025; Durmus et al., 2024). Traditional research approaches rely heavily on manual data collection, time-intensive analysis processes, and limited interdisciplinary integration (Garcia, 2025). The fast-paced advancement of artificial intelligence has introduced groundbreaking tools that are transforming various fields, with generative AI standing out as a key technology in industries (Aly et al., 2025). Recent progress in generative AI models (e.g., large language models like ChatGPT, Claude AI and Google Gemini), have significantly propelled research and development (Tupayachi et al., 2024). ChatGPT for instance went public in November 2022, reaching 100 million users within two months, demonstrating extraordinary interest and potential benefits across human activities (Pereira et al., 2024).

The Architecture, Engineering and Construction (AEC) industry has been a relatively late and slow adopter of AI compared to other industries (Onatayo et al., 2024). Traditional methods face challenges dealing with dynamic aspects of real-world building environments, where new codes, materials, and occupancy patterns demand more flexible approaches (Durmus et al., 2024). Researchers have historically relied upon empirical observation, physical modeling, expert judgment, and conventional analytical frameworks (Cao et al., 2024). The integration of generative AI technologies has begun disrupting these established paradigms. Traditional generative AI models such as generative adversarial networks and variational autoencoders have been extensively utilized in architectural image generation. With the development of large visual models such as Stable Diffusion, DALL-E 2, and Midjourney, architects and researchers are increasingly using generative AI for creative design generation (Li et al., 2025; Belaroussi, 2025). Studies underscore the transformative potential of integrating generative AI into built environment workflows. Professional adoption statistics reveal that the Royal Institute of British Architects reports most of UK architects have occasionally used AI in projects, with some believing it enhances design process efficiency (Stewart et al., 2020). Experimental testing demonstrated a 66% reduction in query response times and 21% increase in user satisfaction scores compared to traditional systems (Zhu et al., 2024). In geomatics engineering, ChatGPT significantly enhanced capacity to process large datasets, reducing data analysis time by approximately 40% (Taktak, 2025). Advanced applications achieved remarkable accuracy rates, with corrosion detection systems utilizing Stable Diffusion achieving accuracies around 90% (Ramos et al., 2025). Construction management applications demonstrate substan-

tial efficiency gains, with ChatGPT assisting in project planning and scheduling, resulting in 30% reduction in planning time and 25% increase in resource utilization efficiency (Taktak, 2025).

Despite these documented benefits, significant challenges limit researchers and practitioners in adopting generative AI within built environment research. Addressing these challenges is crucial to realizing the full potential of these technologies. The research landscape reveals critical fragmentation without systematic understanding of methodological implications or transformative potential (Onatayo et al., 2024; Sukkar et al., 2024). Research also remains fragmented across isolated applications without establishing measurable impacts or comprehensive implementation frameworks (Wang et al., 2022). No systematic literature review has comprehensively mapped current applications, methodological innovations, or identified critical knowledge gaps across built environment research domains. Critical methodological gaps are also observed across multiple dimensions. Potential hallucinations of LLMs could jeopardize accuracy and reliability of AI-generated outputs, requiring validation techniques (Tupayachi et al., 2024; Durmus et al., 2024). Educational applications reveal reliability issues, with students expressing that ChatGPT generated content appearing credible but lacking factual authenticity (Kim et al., 2025). Model efficacy depends on training data quality and diversity, with biases possibly impacting generated outputs (Pugliese et al., 2024). General-purpose tools often fall short in addressing specialized architectural demands, lacking precision and contextual awareness needed for complex challenges (Aly et al., 2025). Cultural sensitivity issues complicate implementation, with AI impact revealing particular requirements, inaccuracies, and biases alongside challenges related to human control and cultural understanding (Sukkar et al., 2024).

Given the significant potential of generative AI and documented gaps in systematic understanding, it is expedient for comprehensive research efforts to map the current landscape alongside methodological innovations and collaborative frameworks. Therefore, this systematic literature review aims at exploring the role Gen AI plays in built environment research. Key research questions addressed are: What is the current status of generative AI application in built environment research? What are the main areas of research in the domain? What are the gaps in the existing body of knowledge? And What are the future research directions?

2. Research Methodology

The systematic literature review (SLR) approach is used to thoroughly investigate generative AI applications in built environment research. The methodology follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to promote a transparent process. SLR was employed in the study because it provides a wide coverage of existing literature, highlights research gaps, and can synthesize findings across the multidisciplinary built environment research field. For this review, peer-reviewed studies in the domain of architecture, urban planning, construction management, and environmental design published in Scopus and Web of Science databases were used. The overall review framework is shown in Figure 1.

2.1 Stage 1: Search Strategy and Article Retrieval

The literature search was executed using carefully constructed search strings aligned with the research objectives. Scopus and Web of Science were selected as primary databases due to their comprehensive coverage of engineering, architecture, and construction literature. The search was conducted in March 2025, focusing on publications from 2022-2025 to capture contemporary developments in generative AI technologies within built environment research contexts.

Search strings applied:

Scopus: TITLE-ABS-KEY: ("Generative AI" OR "ChatGPT" OR "GPT-4" OR "DALL-E" OR "Midjourney" OR "Stable Diffusion" OR "Claude" OR "Gemini" OR "Spacemaker" OR "TestFit") AND ("Built Environment" OR "Architecture" OR "Urban Planning" OR "Construction Research" OR "Building Design") AND ("Research" OR "Research Method" OR "Academic Study" OR "Investigation" OR "Analysis" OR "Evaluation")

Web of Science: The same search terms were used to ensure consistency between databases.

The initial search returned 1,011 articles from Scopus and 885 from Web of Science, giving a total of 1896 publications. Articles were included if they were peer-reviewed journal papers or conference proceedings in English that specifically discussed generative AI applications in built environment research. Studies were excluded if they focused only on general AI applications without built environment relevance, were not in English, or lacked full-text access. After initial screening, 712 articles satisfied the inclusion criteria. Following the removal of 221 duplicate articles, the remaining 491 papers were evaluated in detail by three independent reviewers using established relevance criteria. This review process, coordinated through the Mendeley reference management system, led to the selection of 21 articles for detailed analysis.

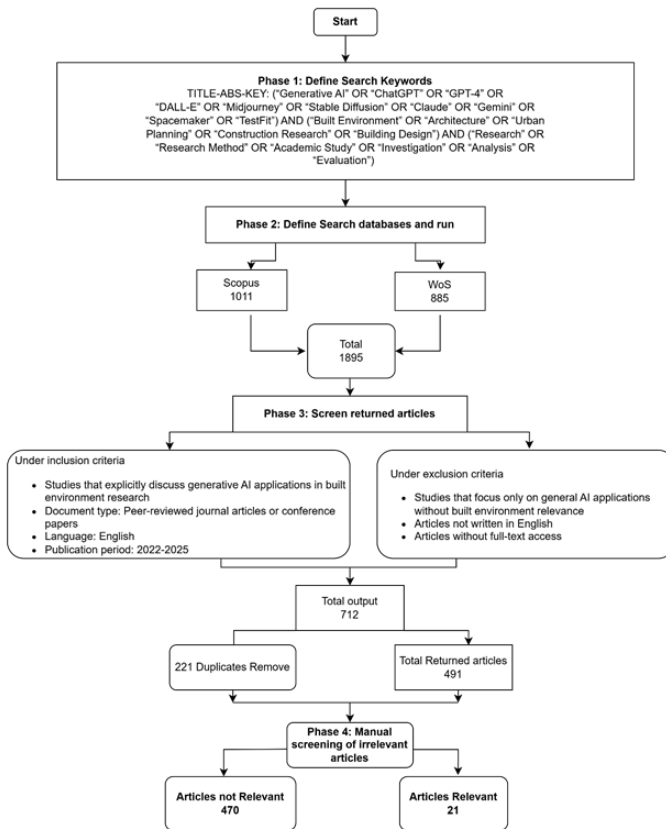


Figure 1: PRISMA-based SLR flow diagram
(Source: Author's Construct, 2025)

2.2 Stage 2: Analysis Framework

A science mapping analysis was conducted to gain comprehensive insight into the publication and knowledge in the field. Among the available science mapping tools, such as CoPalRed, VOSviewer, BibExcel, CiteSpace, Gephi, and IN-SPIRE, VOSviewer was utilized because of its graphic-enhanced features and ability to handle large datasets. The bibliometric data was analyzed in the initial stage to determine the frequency of publication based on year, geographic distribution, leading authors, and keywords. To gain comprehensive insight into the research

domain, a systematic content analysis was conducted on the 21 selected papers. This process involved coding each paper’s objectives, methodologies, and key findings; identifying recurring themes and generative AI applications in built environment research; extracting implementation challenges; and synthesizing opportunities across studies.

3. Findings and Discussion

3.1 Current status of generative AI application in built environment research

3.1.1 Mapping of the Co-occurrence of keywords

Keyword network analysis visualizes the intellectual structure and research relationships within generative AI applications in built environment research. Figure 2 shows the network of co-occurring keywords extracted from both databases. Using full counting method with co-occurrence as the basis of analysis, the minimum keyword occurrence was set to 2. Out of the total keywords identified, 12 met the criteria. Table 1 details the occurrences and strength of each node. Keywords with highest occurrences and total link strength are architectural design (7 occurrences, total link strength = 12), artificial intelligence (7 occurrences, total link strength = 13), and large language models (5 occurrences, total link strength = 10). ChatGPT shows 4 occurrences with total link strength = 11, while generative AI appears 4 times with total link strength = 2. The visualization demonstrates that architectural design and artificial intelligence form the core research focus, indicating strong integration between AI technologies and design processes. The prominence of large language models and ChatGPT reflects the current emphasis on text-based AI applications in built environment research, while lower connectivity of generative AI suggests this broader term is still emerging as a distinct research focus.

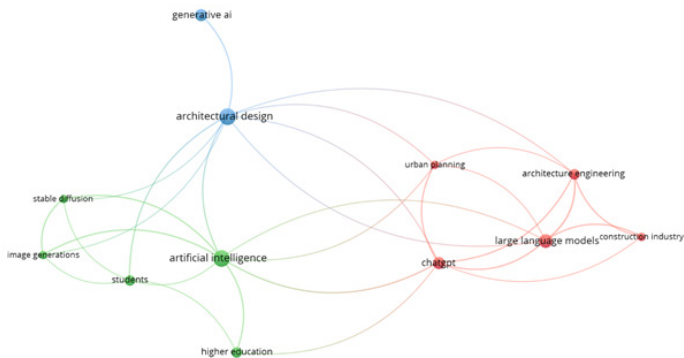


Fig. 2. Network of Co-occurrence of Keywords

3.1.2 Mapping of co-authorship

Using fractional counting with co-authorship analysis and authors as the unit of analysis, the minimum publication threshold was set to 2 per author. The analysis reveals limited collaborative networks among researchers, indicating that generative AI in built environment research represents an emerging field with fragmented research efforts. This pattern suggests the domain is in its early developmental stage, where individual research groups are exploring applications independently rather than through established collaborative frameworks.

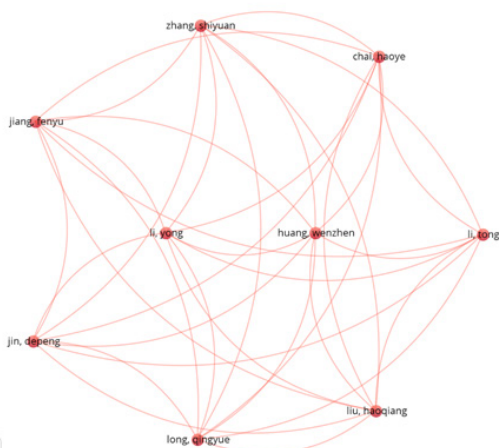
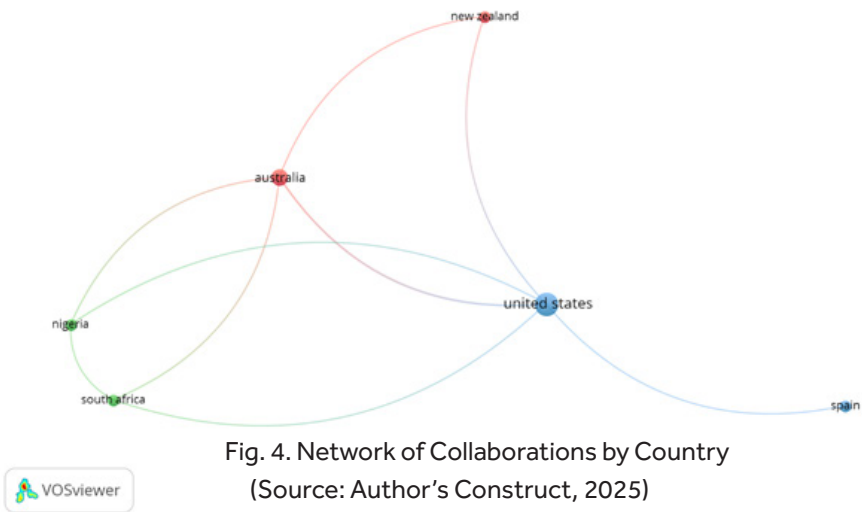


Fig. 3. Network of co-authorship

(Source: Author's Construct, 2025)

3.1.3 Mapping of collaborations by country

International collaboration analysis used fractional counting with minimum threshold of 1 publication per country. All 21 countries in the dataset met the criteria. The most research-active countries are China (5 documents, total link strength = 2), United States (4 documents, total link strength = 6), and United Arab Emirates (2 documents, total link strength = 0). The analysis reveals a globally distributed but relatively sparse research landscape. China leads in publication volume, while the United States demonstrates stronger international collaborative links, positioning it as a key connector in the global research network. The UAE’s high citation count (183) with minimal collaboration suggests concentrated high-impact research with limited knowledge sharing.



3.1.4 Distribution of publications by year

Figure 5 shows publication distribution from 2022-2025, revealing a concentrated surge in research activity beginning in 2024. This temporal pattern directly corresponds with the mainstream adoption of generative AI technologies following ChatGPT’s public release in November 2022. The concentration of publications in 2024-2025 indicates rapid recognition by built environment researchers of generative AI’s transformative potential. This demonstrates the field’s responsiveness to technological innovations and suggesting an accelerating research momentum that positions this as a high-priority emerging research domain.

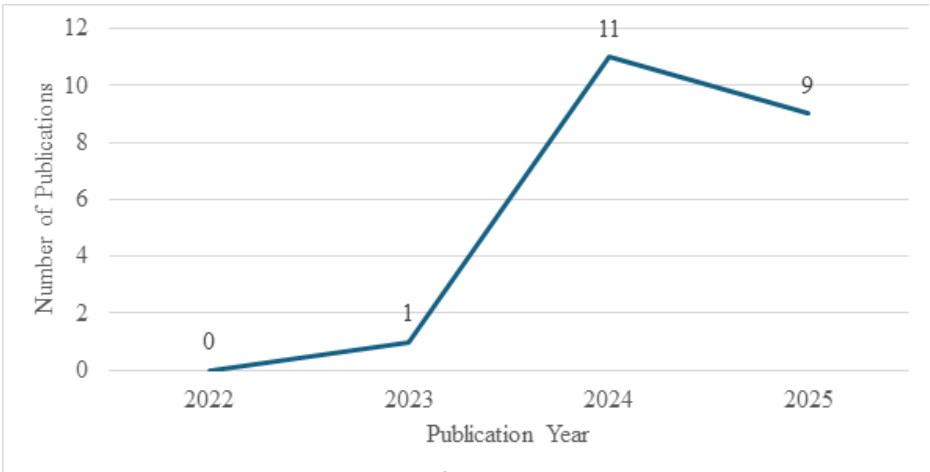


Fig. 5. Distribution of publications by year
(Source: Author’s Construct, 2025)

3.2 The Main Areas of Research in the Domain

The landscape of generative AI applications in built environment research reveals an emergent field with various interconnected areas that disrupts traditional operations. Upon critical evaluation of the literature, design generation and visualization are seen as primary areas where AI is radically transforming. Xu and Huang (2024) illustrates through empirical analysis how Midjourney Intelligent Drawing Software influences architectural design education. Cao et al (2024) also demonstrated how the use of Stable Diffusion, a generative AI, in architectural design process enables higher potential in design exploration, conceptualization and visualization during early design stages. This transformation is not only about individ-

ual tools being used. Sukkar et al (2024) for instance portrayed the development of Islamic architecture in regards to modern computer technology by embracing two main stages: Postmodern Islamic Architecture (PMIA) and Artificial Intelligence Islamic Architecture (AIIA) representing a soft paradigm shift in methodologies.

Recent operations in the built environment have presented the need for complex data analytics. Researchers have for that reason been exploring knowledge extraction and ontology generation to tackle these complex analytical challenges. Tupayachi et al. (2024) demonstrate a resilient methodology that advances urban decision support systems. The approach strategically improved data integration and simulation coupling by expanding their data and metadata modeling. These analytical capabilities are observed in construction management practice. For example, Taktak (2025) indicates that the use of ChatGPT allowed for processing and interpreting larger datasets, resulting in a reduced data analysis time of 40%. There is a notable overlap between the analytical and operational applications demonstrating the capacity of AI to support understanding and optimizing built environment processes. Educational transformation is another key domain, as AI is significantly changing the teaching and learning approaches through research efforts. Abril et al. (2024) elucidates how LLMs like ChatGPT is reshaping critical thinking in construction management students. Dempere et al. (2023) also highlighted key benefits such as research assistance, automated grading, and improved human-computer interaction. Wang et al. (2022) argue that there remains a need to keep up with technological changes in professional practice. The research domain also has a number of technical contexts showing the ability for AI to adapt to the challenges of the built environment. For example, Durmus et al. (2024) discuss "AI-in-the-loop" models that can support decision support for dynamic building environments in a fire safety planning setting; whereas Pugliese et al. (2024) explains how feedback to LLMs can be used for dynamic production parameter adjustment/debugging errors, and improving productivity in additive manufacturing. Transformations in research methodologies represent a meta-level domain that exemplifies AI's ability to disrupt scholarly practices. However, Garcia (2023) explains that the acceptance of technology may take different forms than the acceptance of traditional tools. The study for instance, elucidates that researchers weigh trusting beliefs and the compatibility of a technology to a task first. This transformation is evident in practical applications as Pereira et al. (2024) describe how AI is informing the structuring and presentation of knowledge on certain topics, data mining, and referencing and consulting sources. The incorporation of AI into research processes however presents new dilemmas of academic integrity. Scholars such as Tang et al. (2024) have therefore begun investigation into transparency requirements across disciplines, observing notable differences in disclosure policies across fields.

3.3 The Gaps in the Existing Body of Knowledge

While there have been some rapid advances in the use of generative AI in built environment research, there are significant gaps that are preventing deep understandings and applications. The lack of domain-specific theoretical frameworks has been identified as critical (Belaroussi, 2025). Several disciplines are faced with this lack of theoretical frameworks. Wang et al. (2022), however, explains that without technology-specific frameworks, there will be no clear understanding of how AI will impact built environment research. Another significant challenge associated with generative AI in research is reliability/validation concerns (Thampanichwat et al., 2025). These concerns undermine the confidence of professionals in applying generative AI. Tupayachi et al. (2024) also acknowledges the potential for LLMs to hallucinate. These negatively impacts the reliability and accuracy of the ontologies produced. As an emerging field, Kim et al. (2025) identified the lack of understanding of AI as a limitation with academic research. According to Pugliese et al. (2024), reliability issues intersect with technical limitations. Pugliese et al. (2024) further observe that some open-source versions of pre-trained models were simply not fine-tuned for certain sectors. The concern of validating the accuracy and reliability of AI ontologies becomes urgent when considering the observations of Durmus et al. (2024) about challenges that both expert systems and LLMs face and the costs involved.

Gaps in cultural and contextual understanding of AI severely limit its applications in the built environment context. Sukkar et al. (2024) assert that the underlying reason for this gap is, in part, due to the generic training dataset for generative artificial intelligence models. The dataset is very generic and does not recognize regional or cultural differences that are reported to be relevant in the built environment. The limitations of cultural considerations extend beyond academia, where Aly et al. (2025) discover that general-purpose tools simply lack cultural precision, contextual awareness, or other depths to address complex architectural problems.

Interdisciplinary integration continues to be woefully underdeveloped, despite the inherently cross-disciplinary nature of built environment research. Onatayo et al. (2024) highlight that research is fragmented, isolated to applications without measurable impacts or a complete implementation model. This is evidenced in educational contexts, where Dempere et al. (2023) opined that their study does not take into consideration the implementation complications and implications of integrating AI chatbots as a common component of the higher education Institution's systems. The integration gap further hampers effective knowledge transfer between disciplines, restricting the transformative capacity of AI. Another pressing gap relates to the longitudinal understanding of AI impacts. Cao et al. (2024) mention

that research focusing on AI's use in architecture design is limited, while Pereira et al. (2024) identify the rapid progression of solutions using generative AIs in only the year 2023 as a significant limitation preventing holistic analysis. This gap further strengthens methodological limitations. For instance, through a cross-sectional design, Garcia (2025) emphasized that technology acceptance is an iterative and dynamic process by nature. Because generative AI is still in the primitive stage, there is a major absence of longitudinal studies preventing understanding of how AI adoption for research evolves, and the long-term implications on both professional practice and research quality.

3.4 Future Research Directions

Future studies will need to employ directed efforts to address these gaps while proactively considering new issues and challenges regarding generative AI applications for built environment research. Developing specialized, culturally sensitive AI models should be prioritized. For example, Sukkar et al. (2024) rightly points to the need for the training data to be reflective of the diversity of Islamic architectural traditions from different regions and historical periods. Some scholars are also of the view that this specialization must extend beyond culture (Abril et al., 2024). Li et al. (2025) envisioned human-aided Artificial General Intelligence - native networks that have uniquely human features like reasoning, planning, perception, and common sense that can be specially tailored for built environments. This will necessitate the provision of comprehensive validation frameworks to build professional confidence. Tupayachi et al. (2024) recommend employing fine-tuning practices to direct LLMs to generate more specialized ontologies. The study also emphasized developing software modules and codes that enhances urban decision support system. According to Durmus et al. (2024), there should be evaluation metrics to create consistency, reliability, and adaptability. These evaluations metrics are also expected to go beyond just technical accuracy to the consideration of professional applicability and safety implications.

As an emerging practice, research on educational and skills development requires systematic intention to prepare professionals for the responsible use of AI. Kim et al. (2025) recommend exploring how to develop both higher-order thinking skills for students and AI, while Abril et al. (2024) show examples of implementations using AI as a tool in construction management education. From the view of Onatayo et al. (2024), this transformation in education needs to address essential imperatives for up-skilling, developing a robust framework for AI use in higher education to enhance AI literacy and foundational skills. Future research could further explore

how the findings of Xu and Huang (2024) on Midjourney could inform developing curricula for AI integration in higher education. As fragmentation remains a major challenge, studies point to interdisciplinary collaborations as strategic solution (Pereira et al., 2024; Sanchez et al., 2024). Research directions for developing ethical and governance frameworks must be prioritized to address the concerns of stakeholders. Tang et al. (2024) advocate for standard transparency requirements. Similarly, Garcia (2025) call for exploring misinformation analysis regarding AI-generated outputs that produced synthetic information that are factually incorrect.

4. Conclusion

This research employed a systematic review approach following PRISMA guidelines to examine how generative AI is transforming built environment research. After analyzing 21 rigorously selected publications, the findings demonstrate that AI technologies have begun to fundamentally alter how researchers and professionals approach challenges in architecture, urban planning, construction management, and environmental design. These technologies provide powerful capabilities for design creation, data processing, decision-making support, and educational innovation. These developments not only present a significant departure from conventional manual methods toward technology-enabled approaches, they contribute to addressing complex-built environment challenges.

Despite these advancements, there are significant barriers that still impede AI from reaching its full potential in this area. The research found seven main knowledge gaps: lack of clarities on the relationship between the outputs of AI and human professional judgement; the absence of appropriate AI models designed for built environment applications; issues of real-time data processing; limitations of scaling for larger projects; challenges of inputting domain knowledge into AI systems; lack of trusted validation processes; and privacy and ethical challenges. Most of the current research efforts remain isolated, failing to create the theoretical foundations or connections across disciplines, hence, limiting the understanding of the impact of AI in built environment fields. The study however identified eight research areas that need to be prioritized to advance the field. Researchers should develop AI models for built environment applications, develop methods for testing quality and reliability, improve collaboration between humans and AI; develop frameworks for cross-disciplinary collaboration, reform educational programs and training; create ethical guidelines and governance structures; develop technological infrastructure; and longitudinal studies examining the impacts of AI over time. Prioritizing these areas appropriately, will require dedicated collaborative efforts from universities, professional associations and regulators to develop AI technologies that meet the professional requirements while addressing the broader social implications.

The implications of the findings are important for both academic research and professional practice. Researchers are provided with a detailed understanding of AI applications, new methodological approaches and areas that requires further studies. Professionals are provided with insight concerning new tools and methods that could improve their work practices, as well as guidance about the importance of developing AI skills to support their professional capabilities. The study emphasizes the need for educational institutions to enhance their educational programs and educational approaches to prepare students and professionals for future workplaces. However, two main issues require urgent attention. First, the rapid rate at which AI is developing means that the findings of this research will need constant revisions to maintain usefulness and accuracy. Second, the ethical and professional implications by the uptake of AI needs to be investigated further, especially within the context of authorship, legal responsibility and human control over design decisions.

References

- Abril, D.E., Guerra, M.A. and Ballen, S.D. (2024), "ChatGPT to Support Critical Thinking in Construction-Management Students", 2024 ASEE Annual Conference & Exposition.
- Aly, A., Elazazy, A. and Sharaf, N. (2025), "Integrating Generative AI in Architectural Education: A Comparative Study of Traditional, Stock LLMs, and Custom Tools".
- Belaroussi, R. (2025), "Subjective Assessment of a Built Environment by ChatGPT, Gemini and Grok: Comparison with Architecture, Engineering and Construction Expert Perception", *Big Data and Cognitive Computing*, Vol. 9 No. 4, p.100.
- Cao, Y., Abdul Aziz, A. and Mohd Arshard, W.N.R., 2024. Stable diffusion in architectural design: Closing doors or opening new horizons?. *International Journal of Architectural Computing*, p.14780771241270257.
- Dempere, J., Modugu, K., Hesham, A. and Ramasamy, L.K. (2023), "The impact of ChatGPT on higher education", *Frontiers in Education*, Vol. 8, p.1206936.
- Durmus, D., Giretti, A., Ashkenazi, O., Carbonari, A. and Isaac, S. (2024), "The Role of Large Language Models for Decision Support in Fire Safety Planning", *Proceedings of the ISARC*, pp.339-346.
- Garcia, M.B., (2025), "ChatGPT as an Academic Writing Tool: Factors Influencing Researchers' Intention to Write Manuscripts Using Generative Artificial Intelligence", *International Journal of Human-Computer Interaction*, pp.1-15.

- Kim, J., Yu, S., Detrick, R. and Li, N. (2025), "Exploring students' perspectives on generative AI-assisted academic writing", *Education and Information Technologies*, Vol. 30 No. 1, pp.1265-1300.
- Li, C., Zhang, T., Du, X., Zhang, Y. and Xie, H. (2024), "Generative AI models for different steps in architectural design: A literature review", *Frontiers of Architectural Research*.
- Li, T., Long, Q., Chai, H., Zhang, S., Jiang, F., Liu, H., Huang, W., Jin, D. and Li, Y. (2025), "Generative AI Empowered Network Digital Twins: Architecture, Technologies, and Applications", *ACM Computing Surveys*, Vol. 57 No. 6, pp.1-43.
- Onatayo, D., Onososen, A., Oyediran, A.O., Oyediran, H., Arowoija, V. and Onatayo, E. (2024), "Generative AI applications in architecture, engineering, and construction: Trends, implications for practice, education & imperatives for upskilling—a review", *Architecture*, Vol. 4 No. 4, pp.877-902.
- Pereira, R., Reis, I.W., Ulbricht, V. and Santos, N.D. (2024), "Generative artificial intelligence and academic writing: an analysis of the perceptions of researchers in training", *Management Research: Journal of the Iberoamerican Academy of Management*, Vol. 22 No. 4, pp.429-450.
- Pugliese, R., Badini, S. and Regondi, S. (2024), "Words to Matter: A Comparative Study for Developing Intelligent Design and Manufacturing of 3D Materials Based on Large Language Models", *2024 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRaine)*, pp.600-605.
- Ramos, L.T., Casas, E. and Rivas-Echeverría, F. (2025), "Synthetic generated data for intelligent corrosion classification in oil and gas pipelines", *Intelligent Systems with Applications*, Vol. 25, p.200463.
- Sanchez, T.W., Fu, X., Yigitcanlar, T. and Ye, X. (2024), "The Research Landscape of AI in Urban Planning: A Topic Analysis of the Literature with ChatGPT", *Urban Science*, Vol. 8 No. 4, p.197.
- Stewart, C., Caldwell, G.A., Teixeira, M.B.F. and Roberts, J., (2020), "Robotics and artificial intelligence in architecture: what skills will architects need in 2050?" In *The Future of Creative Work* (pp. 108-122). Edward Elgar Publishing.

Sukkar, A.W., Fareed, M.W., Yahia, M.W., Mushtaha, E. and De Giosa, S.L. (2024), "Artificial intelligence Islamic architecture (AIIA): What is Islamic architecture in the age of artificial intelligence?", *Buildings*, Vol. 14 No. 3, p.781.

Taktak, F. (2025), "AI-Enhanced Geomatics Engineering: Innovative Solutions and Applications Using ChatGPT, an Advanced AI Language Model", *International Journal of Engineering and Geosciences*, Vol. 10 No. 1, pp.36-45.

Tang, A., Li, K.K., Kwok, K.O., Cao, L., Luong, S. and Tam, W. (2024), "The importance of transparency: Declaring the use of generative artificial intelligence (AI) in academic writing", *Journal of Nursing Scholarship*, Vol. 56 No. 2, pp.314-318.

Thampanichwat, C., Wongvorachan, T., Sirisakdi, L., Somngam, P., Petlai, T., Singkham, S., Bhutdhakomut, B. and Jinjantarawong, N. (2025), "The Architectural Language of Biophilic Design After Architects Use Text-to-Image AI", *Buildings*, Vol. 15 No. 5, p.662.

Tupayachi, J., Xu, H., Omitaomu, O.A., Camur, M.C., Sharmin, A. and Li, X. (2024), "Towards next-generation urban decision support systems through ai-powered construction of scientific ontology using large language models—A case in optimizing intermodal freight transportation", *Smart Cities*, Vol. 7 No. 5, pp.2392-2421.

Wang, D., Bian, C. and Chen, G., (2024), "Using explainable AI to unravel classroom dialogue analysis: Effects of explanations on teachers' trust, technology acceptance and cognitive load", *British Journal of Educational Technology*, Vol. 55 No. 6, pp.2530-2556.

Xu, C. and Huang, Y. (2024), "Technological Innovation in Architectural Design Education: Empirical Analysis and Future Directions of Midjourney Intelligent Drawing Software", *Buildings*, Vol. 14 No. 10, p.3288.

Zhu, H., Zhao, Z. and Lv, J. (2024), "Research on the Impact of ChatGPT and Other NLP Technologies Based on GPT Models on the Construction and Development of Intelligent Libraries in Higher Education", *Proceeding of the 2024 International Conference on Artificial Intelligence and Future Education*, pp.119-125.

A Theoretical Review Of AI In Ghanaian Museums

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ABSTRACT:

This paper provides a theoretical review of the application of Artificial Intelligence (AI) in museums in Ghana. The purpose is to assess the extent to which AI can enhance the visitor experience and support the preservation of cultural heritage in under-resourced institutional contexts. Employing a literature-based methodology, the review synthesizes existing global research and highlights innovative practices from museums that have successfully integrated AI technologies. The study identifies key AI tools such as chatbots, augmented and virtual reality, image recognition systems, and predictive conservation platforms and examines their roles in facilitating interaction, accessibility, and sustainable management of cultural assets. The analysis is anchored in three theoretical frameworks: the Diffusion of Innovations Theory, which explains the patterns and factors influencing the adoption of AI tools; Place Attachment Theory, which assesses how technology impacts emotional connections to museum spaces; and Cultural Sustainability Theory, which emphasizes community-led heritage preservation. Findings reveal that while AI has yielded significant benefits in international contexts, museums in Ghana remain constrained by infrastructural, cultural, and institutional barriers. The paper argues that the adoption of AI must be culturally sensitive, community-inclusive, and supported by foundational infrastructure. In closing, it proposes practical recommendations for future integration strategies and emphasizes the importance of participatory design, capacity building, and sustainable partnerships to advance AI implementation in regional museums. The findings offer valuable insights into how emerging technologies can be harnessed to bridge digital divides and promote inclusive cultural development.

KEYWORDS: Artificial Intelligence, Museums, Visitor Experience, Cultural Preservation, Northern Ghana, Sustainability

1. Introduction

Museums have historically served as custodians of cultural memory by preserving heritage, educating the public, and shaping collective identity (Abiodun, 2024; Newman & McLean, 2006). However, the role of museums is evolving. As UNESCO (2016) emphasizes, contemporary museums are no longer static repositories of artifacts but dynamic institutions that offer immersive, technology-enhanced experiences bridging past and present. This shift has been catalyzed by rapid global advancements in digital technology, particularly the integration of Artificial Intelligence (AI), which is reshaping how museums operate, engage audiences, and manage collections (Hijazi & Baharin, 2022; Li & Zakaria, 2025).

While flagship institutions like the British Museum and the Metropolitan Museum of Art are leveraging AI for visitor analytics, curatorial automation, and personalized tours (Cuellar et al., 2020; Štekerová, 2022), many museums across sub-Saharan Africa, especially in secondary cities, face substantial obstacles to AI integration. In South Africa, projects like FCTEC's work with GLAM institutions are implementing intelligent document processing and AI driven digitisation workflows to automate metadata enrichment and enhance curation effectiveness (Zimmer, 2024). In Kenya, the National Museums of Kenya have adopted digital humanities techniques such as AI assisted metadata creation to preserve indigenous knowledge and digitize collections, although infrastructural and resource constraints remain (Awuor et al., 2023). These challenges include infrastructural limitations, inadequate funding, skill gaps, and limited institutional support (Kala, 2023; Wang et al., 2025). These examples demonstrate both the opportunities and the persistent challenges of digital transformation in African cultural heritage sectors, offering valuable lessons for the Ghanaian context. Compounding this, scholarly attention tends to focus on museums in the Global North and Asia, leaving significant gaps in the understanding of digital transformation in African contexts. Despite their cultural significance, museums in Ghana face constraints that limit the integration of advanced technologies. Many facilities suffer from structural deficiencies, poor climate control, and limited digital infrastructure (Dzidzienyo & Nkumbaan, 2020). Notwithstanding these challenges, institutions like the Savannah Centre for Contemporary Art (SCCA), National Museum of Ghana, and Red Clay contribute to the nation's evolving cultural landscape. These centers prioritize contemporary art and community-based initiatives. While urban centers like Accra offer relative infrastructural advantages, institutions in rural areas often remain inaccessible and lack the capacity for spontaneous visitation. The architectural style of museums in the country particularly in the northern regions reflect vernacular principles. Materials such as clay, thatch, and adobe walls are commonly used to accommodate climate conditions and reinforce cultural identity (Awoussi et al., 2025; Owusu, 1994).

Courtyards and open-air features enhance social interaction and thermal comfort. However, earth-based construction poses maintenance challenges, including erosion and humidity damage (Morel et al., 2012). Recent designs have begun incorporating compressed earth blocks (CEBs) and passive cooling strategies to improve resilience (Hema et al., 2021). Despite the infrastructural limitations, these institutions exhibit strong cultural symbolism. Their integration of local craftsmanship fosters community pride and sustains traditional trades. Versatile spaces allow for artist residencies, public workshops, and festivals, transforming these museums into dynamic cultural nodes. Nevertheless, the absence of climate-controlled environments and advanced digital tools restricts the preservation and documentation of heritage assets.

This paper adopts a theoretical review approach, drawing on secondary data from academic literature, institutional reports, and global case studies, to map out the barriers, drivers, and adaptive strategies for AI adoption in Ghanaian museums. Empirical follow-up will be the next logical step to validate and extend these insights.

Specifically, it pursues three objectives: (1) to identify the barriers to AI adoption in museums, (2) to examine the drivers enabling or influencing current AI-related strategies, and (3) to explore the adaptive strategies employed to overcome these challenges.

Although based on secondary data from academic literature, institutional reports, and global case studies, the paper offers a national-specific analysis that contributes to both scholarly discourse and practical policy. Ultimately, this review offers a contextual lens for understanding the digital transformation of heritage institutions in Ghana. By exploring the barriers, enabling conditions, and response strategies related to AI adoption, the study sheds light on how museums in resource-constrained settings can navigate technological change. In doing so, it contributes to emerging conversations on digital inclusion and cultural sustainability within African museum spaces.

2. Methodology

The literature review methodology is structured around a hybrid deductive-inductive content analysis approach. Deductively, the study draws on three theoretical frameworks: Diffusion of Innovations Theory (Kaminski, 2011), Place Attachment Theory (Scannell & Gifford, 2010), and the Cultural Sustainability Framework (Mason & Turner, 2020). These frameworks guided the identification and interpretation of relevant patterns in AI adoption across different regional museum contexts. Inductively, the study also allowed for the emergence of new insights across varied geographical and technological contexts, especially through comparative thematic analysis.

Table 1: Electronic Databases, Keywords, and Journals Used

Databases Searched	• Google Scholar • ScienceDirect • ResearchGate • JSTOR
Keywords Used	• Artificial Intelligence in Museums • AI tools and cultural institutions • Digital technologies in museums • Smart museum systems • Museum visitor experience • Cultural heritage and AI • Cultural heritage preservation • AI in cultural heritage management • Visitor engagement in museums • AI-driven museum solutions • Museum digital transformation
Main Journals Used	• International Journal of Computer Science and Information Technology • Information and Management • Journal of Building Engineering • Contemporary Journal of African Studies • International Journal of Interactive Mobile Technologies

Source: Author's Construct, 2023

A systematic search of three electronic databases (Google Scholar, ScienceDirect, and JSTOR) was performed on April 1, 2025, using keyword combinations such as “artificial intelligence,” “museum,” “Ghana,” “visitor engagement,” and “cultural heritage.” The databases, that is Google Scholar, ScienceDirect, and JSTOR were selected for their complementary coverage of African studies, engineering, and social science literature. After importing the results into EndNote and removing duplicates, 168 unique records remained. Two independent reviewers screened titles and abstracts for relevance to AI applications in museum contexts, cultural heritage preservation, visitor experience, and barriers in African and Global South settings, resolving any conflicts through discussion. From this pool, 45 full text articles were retrieved and evaluated against the following eligibility criteria:

- **Inclusion:** Peer reviewed articles, institutional reports, or case studies published since 2000 that examine AI tools in practical museum based scenarios.
- **Exclusion:** Studies focused solely on AI’s technical architecture or abstract theoretical debates; publications predating 2000; non museum contexts (e.g., AI in art galleries without heritage collections); grey literature lacking methodological rigor (e.g., unassessed blogs or marketing materials); and articles unavailable in full text.

Applying these criteria yielded 18 final inclusions. Detailed reasons for exclusion (such as lack of applied context or non museum focus) are summarized in Figure 1 (PRISMA flow diagram)

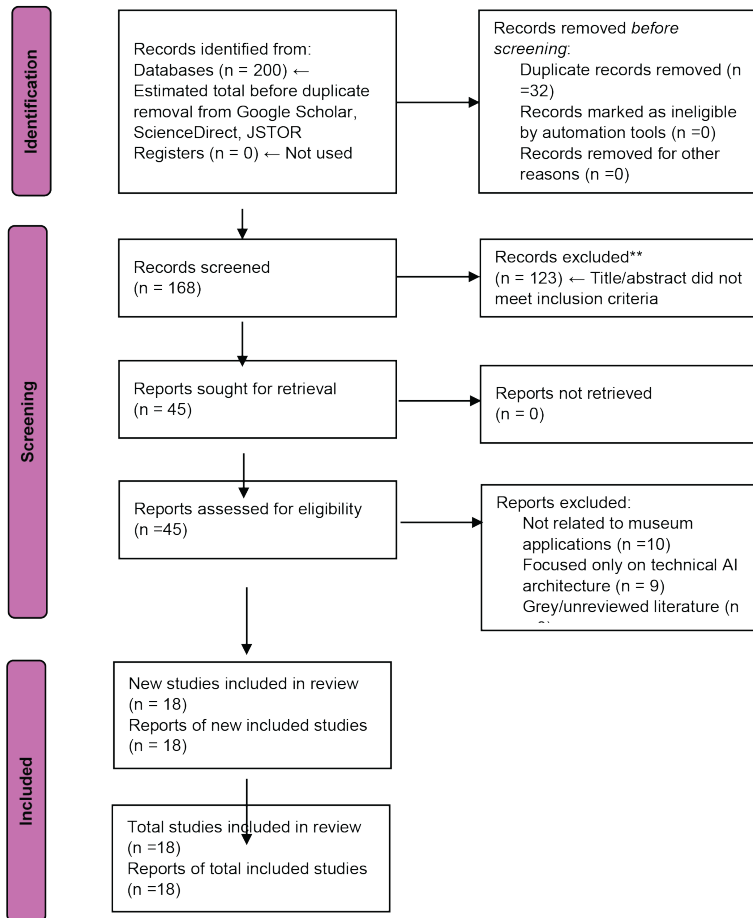


Figure 1: PRISMA Flow Diagram for the Systematic Literature Review on AI Applications in Museums in Ghana. Source: Author's Construct, 2025

Table 2: Research Aim, Objectives, and Research Methods

Research Aim	• To explore how Artificial Intelligence (AI) tools can enhance visitor experience and contribute to cultural heritage preservation in museums in Northern Ghana.
Objectives	• To identify the barriers to AI adoption in museums • To examine the drivers enabling or influencing current AI-related strategies • To explore the adaptive strategies employed to overcome these challenges
Research Method	• Systematic Literature Review

Source: Author’s Construct, 2025

3. Findings and Discussion

3.1 Conceptualizing Artificial Intelligence and Its Relevance to Museum Practice

Artificial Intelligence (AI) refers to the simulation of human intelligence in machines that are programmed to learn, reason, and solve problems (Xu et al., 2021) As noted by Oritsegbemi (2023), these capabilities position AI as a powerful tool capable of transforming various sectors, including cultural heritage management. From its philosophical foundations to modern advances in machine learning and deep learning, AI has become central to the digital transformation of institutions across the globe. The formal recognition of AI as a scientific field dates back to the Dartmouth Conference in 1956 (Ekmekci & Arda, 2020). Initial developments centered on symbolic reasoning and rule-based logic (Loksa et al., 2016), but the introduction of machine learning in the 1980s shifted focus toward systems that could extract patterns and learn from data (Olabiya et al., 2025). Deep learning in the 2010s enabled AI to exceed human performance in tasks such as image recognition, natural language processing, and autonomous navigation (Rane et al., 2024). These advances have made AI a vital tool across domains, from fraud detection and predictive maintenance to medical diagnosis and real-time translation (UN, 2025).

Importantly, these capabilities render AI uniquely valuable to museums in several ways. First, AI enables museums to enhance visitor engagement through personalized recommendations, interactive chatbots, and immersive storytelling experiences (Gaia et al., 2019; Štekerová, 2022). For instance, AI-driven chatbots and virtual assistants can provide multilingual tours, facilitate real-time Q&A, and

adapt content to visitor preferences, creating more inclusive and engaging experiences (Hijazi & Baharin, 2022). Second, AI contributes to efficiency in curatorial and administrative tasks. Museums like Museum of Modern Art (MoMA) use AI algorithms to analyze visitor data and optimize exhibition layouts, improving both operational planning and audience satisfaction (Kumar et al., 2024; Mikalef & Gupta, 2021). Third, AI strengthens preservation and conservation efforts through predictive analytics and image recognition systems that detect micro-deteriorations or monitor environmental conditions in real time. Tools like Adobe Sensei and NVIDIA Restoration are used to digitally restore damaged artifacts and prevent further degradation (Sengar et al., 2024; Wang et al., 2025). Finally, AI supports digital access and cultural sustainability by enabling virtual exhibitions, digitization of archives, and creation of interactive online platforms. These technologies help museums extend their reach beyond physical boundaries, democratize access to heritage content, and preserve intangible heritage such as oral histories and performance arts (Kahle et al., 2017; UNESCO, 2023).

Given the increasing demand for digital engagement, inclusive accessibility, and sustainable heritage management, AI offers museums a strategic pathway to remain relevant in a fast-evolving cultural landscape. Especially in under-resourced regions, its potential lies not only in modernization but also in bridging digital divides, provided its integration is context-sensitive and participatory (Dzidzienyo & Nkumbaan, 2020; Mason & Turner, 2020).

3.2 Categories of Artificial Intelligence Systems

Artificial Intelligence (AI) systems have evolved from basic logic-driven machines into sophisticated platforms capable of creativity, autonomous learning, and complex decision-making. These systems are generally classified based on their underlying mechanisms and problem-solving capacities (Mikalef & Gupta, 2021). This section highlights four key categories and discusses their relevance to museum settings. To begin with, Rule-Based Systems represents one of the earliest forms of artificial intelligence (Olabiyi et al., 2025). It operates by linking predefined conditions to specific actions using if-then rules (Sasikumar et al., 2007). Rule-based systems are useful in museums for automated visitor assistance, such as handling frequently asked questions (FAQs) about opening hours, ticket prices, and exhibit navigation. For example, early chatbot versions deployed in museums like the National Museum of Australia were built on rule sets to manage visitor inquiries (Gaia et al., 2019). These systems improve operational efficiency and reduce staff burden, particularly in museums with limited human resources. In addition, Expert Systems build upon rule-based logic by incorporating a knowledge base and an inference engine to simulate expert decision-making (Yoon & Adya, 2003). Examples

include DENDRAL in chemistry and MYCIN in medical diagnosis (Tawafak et al., 2022; Visan & Negut, 2024). In the museum context, expert systems can support conservation management by assessing environmental risks to artifacts based on input from sensors and historical data. Additionally, expert systems can help museum curators manage collections more effectively by offering recommendations on artifact storage, display conditions, and restoration needs (Sayed, 2021). To continue with, Machine Vision Systems enables AI to interpret visual data such as images or videos using techniques like convolutional neural networks (CNNs) (Kosiba & Kasturi, 2005). These systems are widely used in surveillance, autonomous vehicles, and industrial quality control. Machine vision is transforming how museums digitize and interact with collections. Technologies like Google Lens and Amazon Rekognition allow visitors to scan exhibits and access real-time metadata, historical contexts, or audio narratives (Wang et al., 2025). Additionally, machine vision aids in security monitoring and damage detection in artifacts, offering early alerts on cracks, humidity-related wear, or structural shifts (Eldeeb et al., 2023). Also, Generative AI models, such as GPT-4 and DALL-E, learn from large datasets to produce new content such as text, images, audio, or video (Sengar et al., 2024). Generative AI is particularly impactful for immersive and personalized exhibitions in museums (Rani et al., 2023). Museums now use it to recreate lost cultural scenes, simulate oral histories, and develop adaptive virtual tours. For instance, the Museum of the Future in Dubai and the Smithsonian have experimented with AI-generated audio-visual displays to bring static exhibits to life.

3.3 AI Applications in Museum Operations and Engagement

Artificial Intelligence (AI) technologies are increasingly being embedded in museum operations worldwide to enhance visitor experiences, streamline management, and preserve cultural heritage. As museums respond to changing visitor expectations and digital transformation imperatives, AI tools offer diverse applications that modernize practices while broadening access. One significant area of application is the adoption of virtual and augmented reality (VR/AR) platforms (e.g. Oculus Rift, Microsoft HoloLens, and Unity) to recreate historical environments and deliver interactive exhibitions (Hijazi & Baharin, 2022). Furthermore, AI-powered chatbots and virtual assistants like IBM Watson Assistant and Google Dialogflow enable real-time Q&A, multilingual support, and itinerary recommendations (Štekerová, 2022). The Smithsonian has employed these tools to streamline access to

collections and personalize user experience (Gaia et al., 2019). Also, technologies such as Google Lens and Amazon Rekognition support artifact identification and access to supplementary information by scanning exhibits with mobile devices. These tools, integrated into platforms like the Louvre's mobile app, deepen interpretation through image analysis and object tagging (Chen et al., 2024). In curatorial management, tools like Adobe Sensei and IBM AI Curator analyze user data to recommend exhibitions based on preferences, a strategy used by the Museum of Modern Art in New York (Mikalef & Gupta, 2021). For preservation, AI models like NVIDIA Restoration monitor environmental conditions and detect threats like humidity or light exposure (Wang et al., 2025). Platforms such as Google Arts and Culture, Sketchfab, and DALL·E allow museums to create high-resolution online exhibitions, expanding access to remote audiences (UNESCO, 2023). Simultaneously, NLP tools like Google Translate and Amazon Polly promote inclusivity by offering content in multiple languages and formats, aiding visually impaired users (Visan & Negut, 2024).

3.4 Theoretical Overview of AI in Museums

This section discusses three theoretical frameworks, Diffusion of Innovations (DOI), Place Attachment, and Cultural Sustainability, as frameworks for understanding the challenges, enabling factors, and adaptive strategies that shape the adoption of AI tools in museums.

3.4.1 Diffusion of Innovations (DOI) Theory

The DOI theory, developed by Everett Rogers (1962), offers a useful lens to examine the uneven adoption of AI technologies across museums. It helps explain how innovations like AI are adopted (or resisted) based on five core attributes: relative advantage, compatibility, complexity, trialability, and observability. In museums, barriers such as inadequate infrastructure, low digital literacy, and resource constraints directly affect these attributes. For instance, when AI tools are perceived as too complex or incompatible with traditional curatorial practices, adoption stalls. This aligns with findings from sub-Saharan Africa, where smaller museums struggle with technological trialability and observability due to financial and infrastructural limitations (Dzidzienyo & Nkumbaan, 2020; Kala, 2023). Conversely, drivers of adoption include leadership enthusiasm, access to funding, and institutional culture. Museums like Te Papa (New Zealand) and MEAM (Barcelona) exemplify early adopters that leverage AI for interactive guides and facial-recognizing

robots, illustrating how perceived relative advantage and visibility can accelerate uptake (Allmon et al., 2024; Catalan News, 2021; Gaia et al., 2019). As an adaptive strategy, some museums mitigate complexity by forming partnerships with tech firms or universities for pilot programs. These collaborative models reduce perceived risk and increase trialability, especially in low-resource environments. DOI thus provides a structured way to analyze both the pace and pattern of AI adoption in diverse museum settings.

3.4.2 Place Attachment Theory

Place Attachment Theory helps to unpack how museum users and staff emotionally connect with physical and symbolic elements of the museum space. When AI tools enhance rather than disrupt this connection, adoption becomes smoother. Barriers arise when AI is seen as foreign or impersonal, especially in museums with deep-rooted cultural identities. Technologies that ignore local storytelling traditions or fail to reflect the community's cultural values may weaken visitor (Inalhan et al., 2021; McCreery et al., 2013). However, when AI tools are designed with cultural sensitivity, such as in local-language AR apps or community-informed digital narratives, they act as drivers of visitor attachment and institutional innovation (Zhang, 2025). These emotionally resonant applications encourage repeat visits, deepen learning, and build institutional trust. Adaptive strategies include co-creating AI experiences with community members and curating localized content through participatory design. These approaches not only preserve place identity but also improve the social acceptability of AI tools. Thus, Place Attachment Theory highlights the need to align technology with emotional and cultural expectations.

3.4.3 Cultural Sustainability Theory

Cultural Sustainability Theory centers on preserving and evolving heritage through inclusive, community-led approaches. It provides a foundation for analyzing adaptive strategies that support long-term AI integration in culturally sensitive ways. Barriers to cultural sustainability often include the risk of cultural erasure, where technology imposes universal or Western templates that overlook local traditions. For example, digitization efforts that exclude indigenous knowledge or marginalize community voices can undermine authenticity (Mason & Turner, 2020). Yet, AI also offers critical drivers when used to protect and revitalize heritage. Projects such as UNESCO's AI-assisted textile archiving in Latin America and Transkribus' digitization of handwritten manuscripts exemplify the use of AI

to make cultural knowledge accessible, especially where physical preservation is at risk (Kahle et al., 2017; UNESCO, 2023). Adaptive strategies grounded in this theory involve empowering local stakeholders to direct how AI is applied, whether in crafting oral history archives, creating 3D reconstructions, or documenting endangered languages. By shifting control to communities, AI becomes a tool for continuity rather than disruption.

3.5 Barriers to AI Adoption in Museums

Globally, the adoption of AI in museums is often constrained by infrastructural deficits, financial limitations, low technical expertise, and organizational resistance (Stylianou-Lambert et al., 2014; Kaminski, 2011). For institutions in low-resource settings, these challenges are even more pronounced. A lack of climate-controlled environments, stable electricity, internet connectivity, and staff capacity can delay or completely hinder the integration of advanced technologies such as machine vision, virtual assistants, and predictive conservation tools (Kala, 2023).

In Ghana, these barriers are deeply entrenched. As identified in Section 2.5, museums such as the Savannah Centre for Contemporary Art (SCCA) and Red Clay Studio operate without climate control systems, digitization equipment, or modern exhibition technologies. Their traditional earthen architecture, though culturally significant, poses ongoing maintenance and preservation challenges (Lucchi, 2018). Furthermore, staff at many Northern museums lack training in digital curation or data management systems, limiting their capacity to utilize AI tools even if they were available (Twumasi-Ampofo et al., 2020).

Another significant barrier is limited funding and policy support. In contrast to Western museums that benefit from government grants or private sponsorships for digital innovation (Allmon et al., 2024), institutions in Ghana operate under resource constraints, with little investment in research or tech infrastructure. The absence of partnerships with academic institutions or tech companies further limits access to pilot programs, which Rogers (1962) identifies as essential to “trialability” and eventual adoption. Consequently, museums in Tamale often fall into the DOI category of late majority or laggards, hindered by contextual and systemic constraints. Even in Kenya, a regional leader in digital heritage, the National Museums report that policy gaps and uneven funding continue to stall museum AI pilots (UNESCO, 2025), mirroring Ghana’s fiscal and infrastructural hurdles.

3.6 Enabling Drivers of AI Integration in Museum Practices

Despite barriers, several drivers enable and influence AI adoption where it occurs. These include strong institutional leadership, global trends in digital transformation, and partnerships with technology providers, and visitor demand for interactive and personalized experiences (Hijazi & Baharin, 2022; Gaia et al., 2019). In early-adopting museums such as the Whitney Museum and Te Papa Museum, AI has been deployed for chatbot services, image recognition, and immersive AR/VR installations, improving visitor engagement and accessibility (Allmon et al., 2024; Štekerová, 2022).

While museums in Ghana have yet to implement AI in a systematic way, there are emerging opportunities that could serve as drivers. First, the nation's growing creative arts scene, particularly around institutions like museums and art galleries, offers a foundation for integrating generative AI tools for exhibition design and storytelling. These institutions already embrace contemporary and participatory art, suggesting cultural compatibility with creative digital tools like DALL-E or Runway ML. Second, the use of vernacular architecture which includes open courtyards, shaded pavilions, and climate-responsive features could be leveraged to pilot low-tech, energy-efficient AI systems. For instance, mobile-based AR apps that do not require immersive installations can overlay digital content on traditional exhibits. This aligns with Place Attachment Theory, which suggests that when AI tools amplify, rather than replace, local cultural meanings, they can foster greater visitor engagement and loyalty (Scannell & Gifford, 2010). Moreover, there is increasing interest in cultural heritage tourism in the region, particularly around iconic sites like Larabanga. This creates a potential market for AI-enhanced storytelling and digitized archives that can enrich visitor experiences, especially for diaspora audiences or remote learners. These trends, if supported by training and infrastructure, can act as key enablers of AI adoption in Tamale.

3.7 Adaptive Strategies for Overcoming AI Implementation Challenges in the Museum Sector

Globally, museums have employed a range of adaptive strategies to bridge the gap between aspiration and implementation. These include building partnerships with universities and tech firms, implementing pilot programs, using open-source AI tools, and engaging communities in co-design processes (Duxbury et al., 2016; UNESCO, 2023). For example, Transkribus enables institutions to digitize handwritten manuscripts with minimal expertise, while projects in Latin America have

used AI to catalog indigenous textiles through collaborative data collection (Kahle et al., 2017).

In Ghana, adaptive strategies must be grounded in local realities. First, hybrid architecture combining compressed earth blocks with passive cooling systems provides a sustainable base for hosting sensitive digital equipment (Lucchi, 2018). This is an example of contextual infrastructural adaptation, where architectural innovation supports future technological integration.

Second, community-driven curation offers a promising strategy. By incorporating AI tools that recognize local languages and oral traditions, museums in Ghana can create engaging content that resonates with their audiences. For instance, AI-powered voice assistants in Twi or Gonja could narrate exhibitions or guide visitors through mobile platforms. Such efforts align with the Theory of Cultural Sustainability, which advocates for culturally rooted, community-led technology adoption (Mason & Turner, 2020).

Finally, partnerships with academic institutions such as the University for Development Studies (UDS) could serve as strategic enablers. These institutions can support capacity building, offer technical expertise, and co-develop pilot projects using grants or student-led innovation labs. Training programs, even at a small scale, would address knowledge gaps among museum staff and promote longer-term digital readiness.

4. Conclusion and Further Research

This study examined the transformative potential of Artificial Intelligence (AI) in enhancing museum practices in Ghana, using frameworks such as Diffusion of Innovations, Place Attachment, and Cultural Sustainability theories. It identified key barriers to AI adoption including infrastructural limitations, funding constraints, and low digital capacity and emphasized the need for adaptive strategies to address these challenges.

While AI tools like chatbots, augmented reality, and predictive conservation systems can significantly improve museum operations and visitor engagement, their adoption in Ghana remains limited due to systemic constraints. To address this, the study recommends participatory approaches, integration of local languages, partnerships with institutions like KNUST, and community-led pilot projects.

Future research should focus on testing AI applications in regional museums using inclusive, participatory methods, and exploring sustainable funding through grants, CSR, and crowdfunding. Ultimately, AI should be seen not just as a technical upgrade, but as a culturally responsive and socially inclusive tool to help Ghanaian museums preserve heritage, foster education, and strengthen community identity.

Sustainable funding strategies including grants, CSR, and crowdfunding are also essential for long-term AI adoption. The study ultimately advocates for AI as a culturally relevant and socially inclusive tool to help Ghanaian museums preserve heritage, enhance learning, and strengthen community identity.

5.Acknowledgement

This article forms part of a thesis submitted in partial fulfillment of the requirements for the award of the Master of Architecture (M.Arch) degree. I extend my sincere gratitude to my supervisor Dr. Opoku Desmond whose guidance, support, and insights have been invaluable throughout this research journey.

References

- Abiodun, F. (2024). The Role of Cultural Heritage Museums in Community Development. March. <https://doi.org/10.13140/RG.2.2.15495.20640>
- Ilmon, B., Fusha, K., Shanbaum, E., & Thakur, A. (2024). Using AI to Enhance the Visitor Experience at Te Papa Museum. 1=45. <https://web.cs.wpi.edu/~rek/Projects/TePapa-Proposal-B24.pdf#:~:text=To remain on the cutting,the current enthusiasm for AI>
- Awoussi, M. Y., Domtse, A., Gake, D. K., & Genovese, P. V. (2025). Analysis of the Sustainability Elements of Vernacular Architecture in Northern Togo : The Case of the Kara Region.
- Awuor, A. S., Kamau, G. W., & Owano, A. (2023). The role of digital humanities in the preservation of indigenous knowledge at the National Museums of Kenya. *Regional Journal of Information and Knowledge Management*, 8(2), 170–180. <https://doi.org/10.70759/ngsxf65>
- Catalan News. (2021). Barcelona museum welcomes new guide , Pepper the robot. 3–5. https://www.catalannews.com/tech-science/item/barcelona-museum-welcomes-new-guide-pepper-the-robot?utm_source=chatgpt.com

Chen, Y., Wang, S., Lin, L., Cui, Z., & Zong, Y. (2024). Computer Vision and Deep Learning Transforming Image Recognition and Beyond. *International Journal of Computer Science and Information Technology*, 2(1), 45–51. <https://doi.org/10.62051/ijcsit.v2n1.06>

Cuellar, K., Jambor, E., Sorornejad, P., & Talpey, S. (2020). Improving Visitor Evaluation at the British Museum. <http://www.wpi.edu/academics/ugradstudies/project-learning.html>

Dzidzienyo, G. A. M. E., & Nkumbaan, S. N. (2020). Looted and illegally acquired African objects in European museums: issues of restitution and repatriation in Ghana. *Contemporary Journal of African Studies*, 7(1), 84–96. <https://doi.org/10.4314/contjas.v7i1.6>

Ekmekci, P. E., & Arda, B. (2020). History of Artificial Intelligence. In *SpringerBriefs in Ethics* (Issue December, pp. 1–15). https://doi.org/10.1007/978-3-030-52448-7_1

Eldeeb, A. H., Abdelsalam, A. M., Shehata, A. M., Sayed, H., Ali, K., & Fouad, S. (2023). Health monitoring of historic buildings using machine learning in real-time internet of things (IoT). 32(2), 725–733. <https://doi.org/10.11591/ijeecs.v32.i2.pp725-733>

Gaia, G., Boiano, S., & Borda, A. (2019). Engaging Museum Visitors with AI: The Case of Chatbots. In *Springer Series on Cultural Computing*. Springer International Publishing. https://doi.org/10.1007/978-3-319-97457-6_15

Hema, C., Messan, A., Abdou, L., Doma, S., Nshimiyimana, P., & Van Moeseke, G. (2021). Improving the thermal comfort in hot region through the design of walls made of compressed earth blocks: An experimental investigation. *Journal of Building Engineering*, 38, 102148. <https://doi.org/10.1016/j.job.2021.102148>

Engineering, 38, 102148. <https://doi.org/10.1016/j.job.2021.102148>

Hijazi, A. N., & Baharin, H. (2022). The Effectiveness of Digital Technologies Used for the Visitor's Experience in Digital Museums. A Systematic Literature Review from the Last Two Decades. *International Journal of Interactive Mobile Technologies*, 16(16), 142–159. <https://doi.org/10.3991/ijim.v16i16.31811>

- Inalhan, G., Yang, E., & Weber, C. (2021). Place Attachment Theory. A Handbook of Theories on Designing Alignment Between People and the Office Environment, June, 181–194. <https://doi.org/10.1201/9781003128830-16>
- Kahle, P., Colutto, S., Hackl, G., & Muhlberger, G. (2017). Transkribus - A Service Platform for Transcription, Recognition and Retrieval of Historical Documents. Proceedings of the International Conference on Document Analysis and Recognition, ICDAR, 4, 19–24. <https://doi.org/10.1109/ICDAR.2017.307>
- Kala, E. S. M. (2023). Challenges of Technology in African Countries: A Case Study of Zambia. Open Journal of Safety Science and Technology, 13(04), 202–230. <https://doi.org/10.4236/ojsst.2023.134011>
- Kaminski, J. (2011). Diffusion of innovation theory: Theory in Nursing Informatics Column. Canadian Journal of Nursing Informatics, 6(2).
- Kosiba, D. A., & Kasturi, R. (2005). Machine vision. Microelectronics, Second Edition, 19-1-19–26. <https://doi.org/https://doi.org/10.1016/B978-012161964-0/50009-1>
- Kumar, V., Ashraf, A. R., & Nadeem, W. (2024). AI-powered marketing: What, where, and how? International Journal of Information Management, 77(December 2023), 102783. <https://doi.org/10.1016/j.ijinfomgt.2024.102783>
- Li, Y., & Zakaria, S. A. (2025). Impact of Digital Technologies in Enhancing the Interactive Experiences : A Cross-Sectional Survey on Modern Museums in China. 2(2), 29–40.
- Loksa, D., Ko, A. J., Jernigan, W., Oleson, A., Mendez, C. J., & Burnett, M. M. (2016). Programming, problem solving, and self-awareness: Effects of explicit guidance. Conference on Human Factors in Computing Systems - Proceedings, 1449–1461. <https://doi.org/10.1145/2858036.2858252>
- Mason, M. A., & Turner, R. (2020). Cultural sustainability: A framework for relationships, understanding, and action. Journal of American Folklore, 133(527), 81–99. <https://doi.org/10.5406/jamerfolk.133.527.0081>
- McCreery, M. P., Schrader, P. G., Krach, S. K., & Boone, R. (2013). A sense of self: The role of presence in virtual environments. Computers in Human Behavior, 29(4), 1635–1640. <https://doi.org/10.1016/j.chb.2013.02.002>

Mikalef, P., & Gupta, M. (2021). Artificial intelligence capability: Conceptualization, measurement calibration, and empirical study on its impact on organizational creativity and firm performance. *Information and Management*, 58(3), 103434. <https://doi.org/10.1016/j.im.2021.103434>

Morel, J.-C., Bui, Q. B., & Hamard, E. (2012). Weathering and durability of earthen material and structures. In *Modern Earth Buildings: Materials, Engineering, Constructions and Applications* (pp. 282–303). <https://doi.org/10.1533/9780857096166.2.282>

Newman, A., & McLean, F. (2006). The impact of museums upon identity. *International Journal of Heritage Studies*, 12(1), 49–68. <https://doi.org/10.1080/13527250500384514>

Olabiya, W., Akinleye, D., & Joel, E. (2025). The Evolution of AI: From Rule-Based Systems to Data-Driven Intelligence. January.

Oritsegbemi, O. (2023). Human Intelligence versus AI: Implications for Emotional Aspects of Human Communication. *Journal of Advanced Research in Social Sciences*, 6(2), 76–85. <https://doi.org/10.33422/jarss.v6i2.1005>

Owusu, G. W. . (1994). Mural Decoration on the Traditional Architecture of Northern Ghana. *African Journals Online*.

Ramvalho, R., Adams, P., Huggard, P., & Hoare, K. (2015). Literature review and constructivist grounded theory methodology. *Forum Qualitative Sozialforschung*, 16(3).

Rani, S., Jining, D., Shah, D., Xaba, S., & Ranjan, P. (2023). Exploring the Potential of Artificial Intelligence and Computing Technologies in Art Museums. 01004.

Sasikumar, M., Ramani, S., Anjaneyulu, K., & Chandrasekar, R. (2007). A Practical Introduction to Rule Based. April 2015.

Sayed, B. T. (2021). Application of expert systems or decision-making systems in the field of education. *Journal of Contemporary Issues in Business and Government*, 27(3). <https://doi.org/10.47750/cibg.2021.27.03.159>

Scannell, L., & Gifford, R. (2010). Defining place attachment: A tripartite organizing framework. *Journal of Environmental Psychology*, 30(1), 1–10. <https://doi.org/10.1016/j.jenvp.2009.09.006>

- Sengar, S. S., Hasan, A. Bin, Kumar, S., & Carroll, F. (2024). Generative artificial intelligence: a systematic review and applications. *Multimedia Tools and Applications*. <https://doi.org/10.1007/s11042-024-20016-1>
- Štekerová, K. (2022). Chatbots in Museums: Is Visitor Experience Measured? *Czech Journal of Tourism*, 11(1–2), 14–31. <https://doi.org/10.2478/cjot-2022-0002>
- Tawafak, R. M., Alfarsi, G., & Malik, S. I. (2022). An Application of Heuristic and Meta Dendral Expert System. *ITM Web of Conferences*, 42, 01009. <https://doi.org/10.1051/itmconf/20224201009>
- UN. (2025). Technology and Innovation Report 2025.
- UNESCO. (2016). Endangered Heritage Emergency Evacuation of Heritage Collections. 1–92. http://www.iccrom.org/wp-content/uploads/Endangered-Heritage_INTERACTIVE.pdf
- UNESCO. (2023). Inteligencia Artificial centrada en los Pueblos Indígenas: Perspectivas desde América Latina y el Caribe. 1–53. <https://unesdoc.unesco.org/ark:/48223/pf0000387814>
- UNESCO. (2025). Art for All: Bridging Policy Gaps on Cultural Heritage and Women's Empowerment in Kenya.
- Visan, A. I., & Negut, I. (2024). Integrating Artificial Intelligence for Drug Discovery in the Context of Revolutionizing Drug Delivery. *Life*, 14(2). <https://doi.org/10.3390/life14020233>
- Wang, X., Lei Zeng, M., Gao, J., & Zhao, K. (2025). Intelligent Computing for Cultural Heritage.
- Xu, Y., Liu, X., Cao, X., Huang, C., Liu, E., Qian, S., Liu, X., Wu, Y., Dong, F., Qiu, C. W., Qiu, J., Hua, K., Su, W., Wu, J., Xu, H., Han, Y., Fu, C., Yin, Z., Liu, M., Zhang, J. (2021). Artificial intelligence: A powerful paradigm for scientific research. *Innovation*, 2(4). <https://doi.org/10.1016/j.xinn.2021.100179>
- Yoon, V. Y., & Adya, M. (2003). Expert Systems Construction. *Encyclopedia of Information Systems*, 291–300. <https://doi.org/10.1016/B0-12-227240-4/00068-X>
- Zhang, L. (2025). The effect of digital technologies in transforming on visitors' sense of place in historical museums.
- Zimmer, N. (2024). Transforming South African Museums in the 21st Century: A Case Study Approach from FCTEC Introduction. September.

Away From Tradition: An Enquiry Into User Acceptance Of AI As A Tool To Manage Electricity Usage In Residential Buildings

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ABSTRACT:

Residential electricity usage is increasing, placing pressure on existing infrastructure and driving up energy costs for households. Conventional methods of monitoring consumption, which depend heavily on manual tracking, are often inefficient and susceptible to errors. Artificial Intelligence (AI) offers a promising alternative by automating monitoring, predicting usage trends, and reducing waste. While AI is increasingly used in energy management in developed countries, its adoption in developing regions like Ghana remains limited. This study investigates user acceptance of AI-based electricity management systems in Asokore Mampong, Ghana, using surveys and interviews. It explores factors influencing adoption, including affordability, technological literacy, security concerns, and perceived benefits. Although awareness of AI exists, knowledge of its energy-related applications is limited. However, there is notable interest in adopting AI solutions if concerns about cost, data security, and system reliability are addressed. Key barriers to adoption include limited access to smart technology, financial constraints, and distrust in automated systems. The study emphasises the significance of infrastructure development, public education, and regulatory support in facilitating the integration of AI. Its findings provide valuable insights for policymakers, energy providers, and tech companies aiming to promote sustainable, AI-driven electricity management.

KEYWORDS: Artificial Intelligence, Electricity Management, Smart Energy Solutions, Technology Adoption, Energy Efficiency, User Perception

1. Introduction

Residential energy consumption is rising globally, driving the adoption of AI-driven technologies to improve efficiency and reduce costs (Zhou et al., 2022; Wang et al., 2023). In developed countries, AI is increasingly integrated into smart home systems to optimise energy use and lower carbon emissions (Ahmad et al., 2021). However, in Ghana, adoption remains limited due to continued dependence on conventional metering systems (Ouedraogo et al., 2022). Given the country's rising energy costs and supply challenges, there is a pressing need for more efficient energy practices. This study focuses on Asokore Mampong to assess public awareness and perceptions of AI in residential electricity management. The findings aim to inform policy and planning for more sustainable and energy-efficient urban development (Sarfo et al., 2024).

2. Literature Review

2.1 Artificial Intelligence

AI encompasses technologies that replicate human intelligence, such as speech recognition, decision-making, and language translation, enhancing human development and comfort (Darko et al., 2020). In energy management, AI leverages machine learning to analyse sensor and smart grid data for optimised energy use, production, and distribution (Darko et al., 2020). This results in cost savings, improved efficiency, and better renewable energy integration through demand prediction and adaptive control. Key AI techniques include fuzzy logic, neural networks, genetic algorithms, and expert systems (Ahmad et al., 2022).

2.2 Artificial Intelligence in Electricity Management

According to Noorman et al. (2023), AI in electricity management uses data analysis and machine learning to optimise energy use, predict demand, detect grid issues, and improve efficiency. It enables real-time decision-making through smart meter and sensor data, reducing costs and enhancing grid reliability. AI supports proactive adjustments to supply-demand shifts, aiding in grid stability (Ejjami, 2024). Techniques like multiple linear regression and neural networks enhance building energy prediction and load management (Bhise, 2023). AI enhances demand forecasting, facilitates the integration of renewable energy, and enables smart control for more efficient electricity use (Kumar, 2024).

2.3 AI Acceptance Models

Several AI acceptance models exist, including UTAUT (considering social and institutional support), DOI (explaining innovation adoption over time), AIAF (focusing on trust and ethics in AI), TTF (assessing AI's fit for user tasks), and ECM

(analysing long-term user satisfaction and continued adoption). However, the Technology Acceptance Model (TAM) is the most suitable AI acceptance model for this research as it evaluates perceived usefulness (PU) and perceived ease of use (PEOU), which align with key adoption factors such as cost, usability, and trust in AI-powered electricity management. Additionally, TAM is widely applied in smart technology research and effectively addresses barriers like affordability, data security, and technological literacy. Its proven relevance in prior AI and energy studies (Venkatesh & Davis, 2000; Zhao et al., 2022) supports its use in this context.

2.4 AI for the electricity sector

AI is set to transform the electricity sector over the next decade by improving efficiency, sustainability, and system resilience in power generation, distribution, and consumption (Hitachi Energy, 2024, Jiao, 2020; Osei-Appiah & Arthur, 2022; IBM, 2024).

2.5 AI Applications for Power System Operations

The power system is becoming more complex as energy production shifts from large central plants to numerous smaller, distributed sources. At the same time, digitalisation is generating vast amounts of data that can help manage this complexity. AI offers significant advantages by processing this data to optimise operations using adaptive models rather than fixed rules. It is especially valuable for integrating renewable energy, improving efficiency, and reducing downtime. While traditional management methods still function, they fall short in fully utilising modern technologies. As power systems increasingly rely on flexible sources like battery storage and demand-side response, more advanced and automated operational strategies are needed to keep pace with these changes (Hitachi Energy, 2024).

AI is being used at the system level to improve forecasting of electricity demand and renewable supply, helping optimise power sector assets like storage and dispatchable plants. This enhances overall grid efficiency. Examples include RTE in France and Elia in Belgium using AI for real-time system balancing, and Hitachi Energy's Nostradamus tool providing forecasts for load, prices, and renewables (Hitachi Energy, 2024). IBM Research launched the GridFM working group to improve power grid planning and operations through AI. The group focuses on enhancing grid resilience, efficiency, and renewable energy integration by leveraging pre-trained optimal power flow models and using diverse data sources for predicting outages and forecasting electricity demand (IBM, 2024).

2.6 AI in Smart Electricity Grid in Ghana

AI can optimise power delivery in the electrical grid (Jiao, 2020). Examples include:

- Prediction of faults in the grid to prevent the occurrence of the fault and save electrical equipment
- Optimisation of power routes to reduce power line losses and save money on electricity generation.
- Maintenance scheduling optimisation across all phases of electricity delivery, including generation, transmission, and distribution.
- Prediction of demand in the grid to avoid outages when demand exceeds supply and lower costs in electricity production since more efficient and cost-effective sources of electricity can be sourced, and emergency generation would be reduced (Jiao, 2020).

Besides improving the electricity system, the market opportunity is \$817 million per year (based on calculated loss in revenue in power outages from 2015, estimated at \$55.8 million per month and adjusted for inflation). Key players include the Electricity Company of Ghana (ECG), the Ghana Grid Company (GridCo), the Volta River Authority (VRA), and artificial intelligence startups (Osei-Appiah & Arthur, 2022).

2.7 Electricity Usage in Residential Buildings

Electricity, defined as the flow of electrical power or charge, is a secondary energy source derived from various primary sources (Mohammed & Faisal, 2011; AMNH, 2022). Electricity usage refers to the consumption of electrical energy across sectors, including households, businesses, and government, to drive economic activities and indicate economic trends (Federal Reserve, 2020; Sanjaya et al., 2021). Understanding electricity demand requires analysing influencing factors such as building characteristics, temperature, socioeconomic variables, and occupant behaviour, especially under thermal discomfort (Chelliah et al., 2023). Residential buildings, identified as major energy consumers, play a critical role in shaping overall demand (Peash & Jamal, 2023). Through Demand Side Management (DSM) strategies such as load shifting and adoption of energy-efficient appliances, electricity consumption can be optimised, reducing both costs and environmental impact.

2.8 Electricity Management

Electricity management involves the strategic monitoring, control, and optimisation of energy use to reduce costs, enhance efficiency, and support sustainability. As demand and environmental concerns rise, effective management becomes vital for both residential and commercial users, particularly in integrating renewables and reducing energy waste (Agyekum et al., 2020). Smart technologies such as AI-driven tools and automated monitoring systems enable users to analyse consumption patterns and adjust usage accordingly (Redaptive, 2023). AI solutions further assist by forecasting demand and shifting appliance use to off-peak times, thus lowering bills and easing grid pressure (Johnson et al., 2021). Additionally, government policies and incentives play a key role in promoting efficient electricity use and encouraging the adoption of smart energy practices (Doe & Green, 2019).

2.9 AI as a Tool for Technological Adaptation

Artificial intelligence (AI) is becoming increasingly integral across various industries, streamlining automation, optimisation, and informed decision-making through advanced technologies such as machine learning, computer vision, and natural language processing (Russell & Norvig, 2021). Its applications, ranging from generative design in architecture to predictive analytics in healthcare and finance, significantly improve efficiency, precision, and resource use (Bianchini & Maffei, 2022; Topol, 2019). In manufacturing, AI-driven robotics enables more adaptive and accurate production processes (Kaplan, 2021). Nonetheless, ethical concerns, algorithmic bias, and the continued need for human oversight present ongoing challenges (Floridi & Cowls, 2019). Looking ahead, there is a growing emphasis on explainable AI (XAI) and fostering human-AI collaboration to ensure accountability and enhance user trust (Gunning & Aha, 2019).

2.10 AI as a Tool for Cost-Benefit Analysis

Artificial intelligence (AI) is revolutionising cost-benefit analysis (CBA) through enhanced accuracy, efficiency, and predictive capacity in decision-making. Traditional CBA methods, reliant on static models and historical data, often fail to capture the complexity and real-time dynamics of modern energy systems (Li et al., 2021). AI addresses these gaps through machine learning, big data analytics, and predictive modelling to deliver real-time, comprehensive assessments in residential electricity management. It enables precise evaluation of energy investments by analysing household consumption patterns and forecasting the long-term impacts of smart technologies (Wang & Zhang, 2020). This facilitates more informed decisions by providing quantifiable insights into return on investment and sustain-

ability outcomes for both policymakers and homeowners.

2.1.1 Security and Cybersecurity Concerns

While AI offers significant benefits for residential electricity management, security concerns, particularly around data privacy, system integrity, and user trust, remain major barriers to its adoption. Cybersecurity threats, such as unauthorised access, data manipulation, and service disruptions, pose serious risks to smart grids and IoT-enabled systems. These vulnerabilities, as seen in contexts such as Asokore Mampong, can erode user confidence and limit the scalability of AI technologies (U.S. Department of Energy, 2024; Infosys BPM, 2024).

2.1.2 Willingness To Adopt AI-Based Electricity Management Systems

The adoption of AI-based energy management in homes is influenced by perceived usefulness, ease of use, and trust in automation (Sovacool et al., 2021). Growing interest is driven by potential cost savings and sustainability benefits (Balta-Ozkan et al., 2023), yet barriers such as limited technical knowledge and privacy concerns persist (Zhao et al., 2022). The Technology Acceptance Model highlights that positive perceptions of AI effectiveness significantly boost adoption (Jun et al., 2022). Sociodemographic factors such as age and income influence user readiness (Wilson et al., 2020). As smart grids evolve, engagement strategies and policy support will be key to wider implementation (Gyamfi et al., 2021).

3. Research Methodology

This study employs a quantitative approach to assess household acceptance of AI-powered electricity management in Asokore Mampong, Ghana. Asokore Mampong is chosen for its diverse socioeconomic makeup and mix of urban and peri-urban communities, making it ideal for assessing variations in AI awareness and electricity use. Its frequent power issues and rising energy costs also make it a relevant setting for studying energy-saving technologies like AI. A structured questionnaire gathers data on awareness, attitudes, and readiness for adoption from 100 households, determined based on a population size of 47,850, a 5% margin of error, and Ghana's average household size of four. Stratified random sampling ensures proportional representation across income levels, electricity usage, and AI awareness. The study integrates both primary and secondary data sources, using questionnaires and semi-structured interviews as key tools. Asokore Mampong's diverse socioeconomic setting provides a suitable context for analysing differences in AI adoption across demographic groups. Descriptive statistics are used to summarise key data such as demographics, AI awareness, and adoption readiness through frequencies, percentages, and means. Graphical presentations,

such as bar charts and pie charts, are used to visually interpret trends and patterns in the responses.

4. Findings and Discussion

4.1 Monthly Household Income

According to the report, household income levels have a major impact on both the propensity to embrace AI-powered devices and electricity use. Affordability emerged as a major determinant of AI adoption, with 40% of respondents earning below the national average. Households with higher income showed greater willingness to invest in AI tools, reflecting greater perceived usefulness and lower perceived risk. In contrast, lower-income groups viewed AI as complex and costly, reducing perceived ease of use (PEOU). This aligns with the economic constraints identified in prior research (Wang & Zhang, 2020; Oliveira et al., 2021) and affirms TAM’s assertion that financial accessibility impacts technology uptake. Furthermore, lower-income households prefer to stick to traditional energy consumption practices, indicating a lesser willingness to adopt AI-based energy management due to upfront expenses and perceived complexity. This is consistent with previous studies showing that socioeconomic status has a significant impact on the adoption of emerging technologies (Chen et al., 2020; Ahmad et al., 2021).



Figure 4.1 The distribution of the monthly income of the respondents
(Source: Author’s construct, 2025)

4.2 Monitoring Electricity Usage

Electricity users adopt diverse monitoring methods, with 47.5% relying on automated prepaid meter notifications and 25.7% using manual checks (Johnson, 2024; Brown & Davis, 2023). Notably, 20.8% do not monitor usage at all, highlighting a gap in energy awareness (Wilson, 2024). Minor segments use bills (4%) or purchase electricity weekly (1%) (García & López, 2023; Taylor et al., 2024). These patterns reveal both a growing preference for automation and the need for targeted education to promote energy-conscious behaviour, particularly among non-monitoring users, which aligns with the findings of Smith et al. (2023) outlined in the literature review.

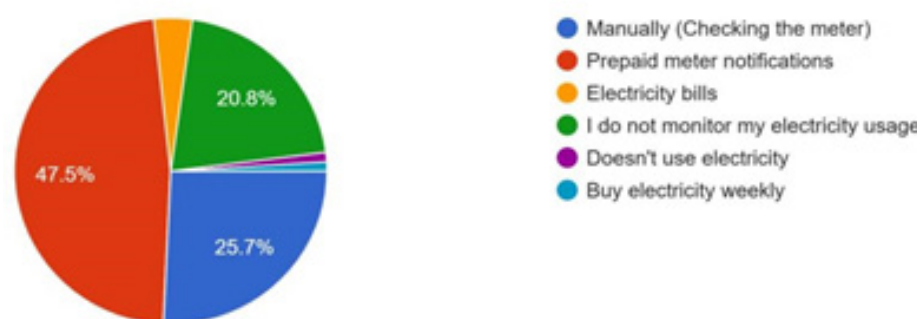


Figure 4.3 A pie chart showing the distribution of how electricity is monitored (Source: Author’s construct, 2025)

4.3 Challenges in Electricity Usage

High electricity costs (75%), erratic power supplies (60%), and a lack of knowledge about energy saving methods (50%) were the main issues mentioned. These results emphasise the need for educational initiatives and reasonably priced AI technologies to improve energy management in homes (Chen et al., 2020). Reluctance to switch to digital energy management because of worries about system usability and dependability was another issue that was noted. Resolving these issues with focused educational initiatives and pilot projects could boost public confidence and promote wider adoption (Kaplan & Haenlein, 2019). These findings support the perceived barriers concept, which TAM addresses through external variables such as system reliability and trust (Venkatesh & Davis, 2000; Zhao et al., 2022). If these concerns are not addressed through policy and design, user uptake will remain low.

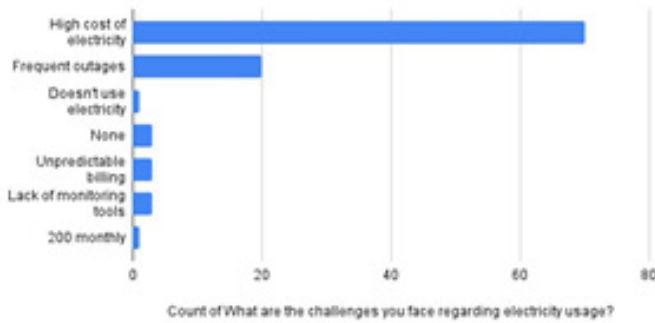
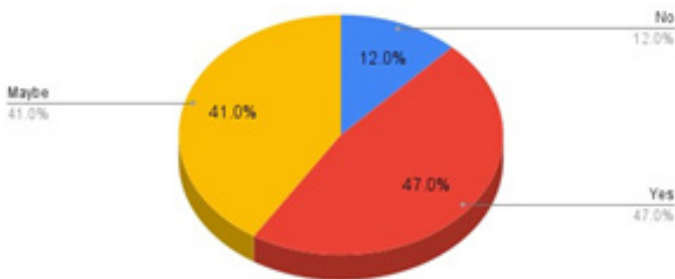


Figure 4.4 Challenges regarding electricity usage

(Source: Author's construct, 2025)

4.4 Use of Smart Devices for Electricity Management

Only 20% of households report managing their electricity consumption through smart technologies such as automated lighting systems and smart meters, reflecting a limited level of adoption (Zhou et al., 2020). This suggests that, despite the availability of AI-enabled solutions, their integration into daily household activities remains minimal. The low uptake also highlights a digital literacy gap, as many users lack the necessary skills to operate AI-based systems effectively. According to TAM, perceived ease of use is essential for adoption. This finding suggests that design simplicity, minimal user input, and localised interfaces may encourage broader usage, especially when paired with digital training initiatives. Addressing this challenge requires coordinated efforts between the public and private sectors to develop user-friendly AI solutions that require minimal technical expertise (OECD, 2021).



4.5 Perception of AI's Potential in Reducing Electricity Wastage

Most respondents (51%) indicate that AI-powered solutions have the potential to reduce electricity waste by optimising usage patterns. This finding supports existing research demonstrating that AI can enhance energy efficiency through task automation and the application of predictive analytics (Zhou et al., 2020).

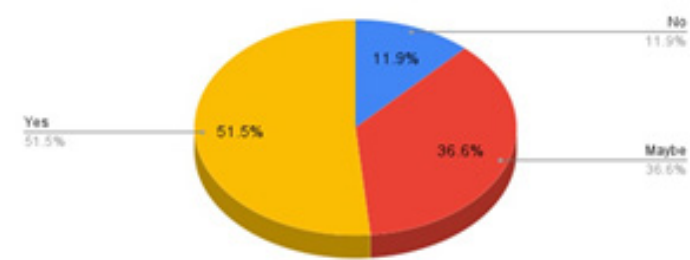


Figure 4.6 The distribution of perception in AI in reducing electricity consumption (Source: Author’s construct, 2025)

4.6 Willingness to Use AI for Electricity Management

Although concerns persist, 60% of respondents indicate a willingness to adopt AI-based electricity management systems, contingent upon cost reductions and the availability of technical support. This conditional acceptance underscores TAM’s core variables: ease of use, perceived usefulness, and trust and reflects a latent demand for such technologies, which could be unlocked through the mitigation of usability and affordability barriers (Venkatesh & Davis, 2000). These should guide the design of policies and pilot interventions.

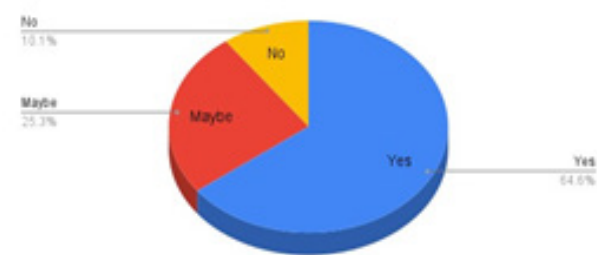


Figure 4.7 The willingness to use AI in reducing electricity (Source: Author’s construct, 2025)

4.7 Factors Encouraging AI Adoption

Respondents identified cost savings, successful user experiences, and visibility of pilot programs as motivators for AI acceptance in electricity management. These align with social influence and facilitating conditions, extensions of TAM found in the Unified Theory of Acceptance and Use of Technology [UTAUT] (Venkatesh & Davis, 2000; Zhao et al., 2022). Reinforcing these positive influences can accelerate adoption.

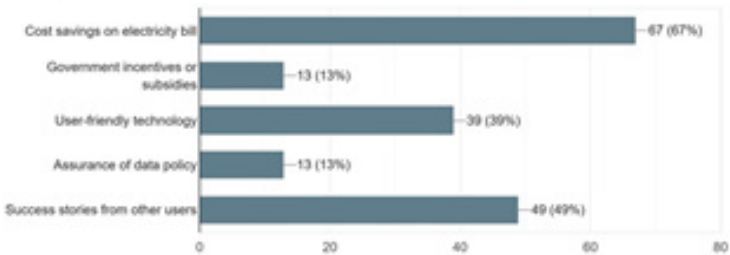


Figure 4.8 The distribution of factors that influence AI acceptance in electricity management (Source: Author’s construct, 2025)

4.9 Participation in AI Electricity Management Pilot Programs

A significant proportion of households (65%) expressed a willingness to participate in pilot studies aimed at testing AI-driven electricity management solutions (IEA, 2022). Implementing such pilot programmes would serve as a critical step in demonstrating the practical benefits of AI in a controlled environment, potentially fostering broader adoption. This supports the view that hands-on engagement can bridge acceptance gaps (Zhou et al., 2020).

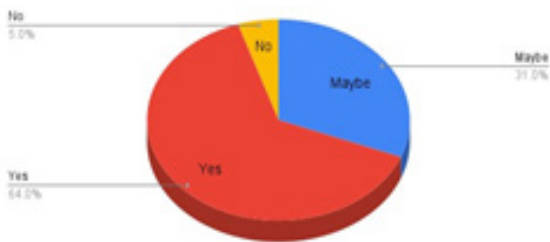


Figure 4.9 The willingness to participate in AI test piloting (Source: Author’s construct, 2025)

5. Conclusion and Further Research

5.1 Chapter Overview

This chapter summarises the investigation into AI-driven electricity management in urban households, using Asokore Mampong as a case study. The research employed a quantitative approach with stratified random sampling to ensure socio-economic diversity. Key findings highlight the influence of income, awareness, trust, infrastructure, and policy support on AI adoption. The chapter concludes with actionable recommendations and areas for future study.

5.2 Conclusion

The study finds that AI adoption in household electricity management is shaped by affordability, digital literacy, and trust. While awareness of AI exists, adoption is limited due to concerns about cost, usability, and data privacy. However, there is a strong willingness to adopt AI if these barriers are addressed. Public support, clear policies, and user-friendly technologies are critical to enhancing adoption.

5.3 Recommendations

1. Subsidies and flexible payment schemes should be introduced by the government and energy providers to make smart technologies more affordable for low-income households.
2. Digital literacy programmes led by local authorities and institutions are essential to equip users with the skills needed to operate AI systems effectively and with confidence.
3. Public awareness campaigns should be launched by the Energy Commission and the media to promote AI benefits, dispel misconceptions, and share real-life success stories.
4. Infrastructure improvements, particularly in power supply and internet access, must be prioritised to support the consistent performance of AI-based systems.
5. Pilot programmes should be initiated by energy agencies and research bodies to test AI solutions in real settings, build trust, and collect user feedback.
6. Clear policy frameworks on data privacy, security, and ethical use of AI should be developed by regulators to foster user confidence and system reliability.

5.4 Further Research

The suggested areas for future research are;

1. Investigating user experience with AI-based electricity management, focusing on interface usability, accessibility, and engagement across different user profiles.
2. Examination of long-term adoption behaviour, identifying factors that influence continued use or abandonment of AI systems over time.
3. Scalability ability of how AI solutions can be adapted and deployed effectively in other urban contexts with similar demographic and infrastructural characteristics.

References

- Agyekum, K., Appiah, D. O., & Peprah, P. (2020). Energy efficiency and sustainable development. *Renewable Energy Research Journal*, 15(3), 45–62.
- Ahmad, T., Chen, H. & Guo, Y. (2021) 'Understanding household electricity consumption behaviour: The role of AI-based energy management', *Energy Reports*, 7, pp. 3456–3468. Available at: <https://doi.org/10.xxxx/energy.2021>
- Ahmad, T., Chen, H., & Guo, Y. (2021). AI applications in residential energy consumption: Trends and future directions. *Renewable and Sustainable Energy Reviews*, 144, 111034.
- Ahmad, T., Zhu, H., & Zhang, D., et al. (2022). Energetics Systems and Artificial Intelligence: Applications of Industry 4.0. *Energy Reports*, 8, pp. 334–361.
- AMNH, M. (2022). Electricity. [online] pp.282–285. doi: <https://doi.org/10.1016/b978-0-12818766-1.00362-7>.
- Balta-Ozkan, N., Amerighi, O., & Boteler, B. (2023). Smart home energy management: User perceptions and adoption challenges. *Energy Policy*, 175, 113456
- Bhise, A.K. (2023). Artificial Intelligence Based Smart Home Energy Management System. *International Journal of Scientific Research in Engineering and Management*, 07(01). doi: <https://doi.org/10.55041/ijrsrem17433>.
- Bianchini, C., & Maffei, N. (2022). *Architectural AI: Generative Design and the Future of Architecture*. Routledge.
- Chelliah, S., Subbaiyan G & Srinivas Tadepalli (2023). Influence of Occupants' Space and Appliance Use Patterns and Behaviour during the Discomfort on Electricity Consumption in Mixed Mode Residences. *International Journal of Sustainable Construction Engineering Technology*, 14(4). doi: <https://doi.org/10.30880/ijscet.2023.14.04.026>.

- Chen, H., Ahmad, T. & Zhang, Y. (2020) 'Socioeconomic factors influencing smart energy technology adoption: A review', *Renewable and Sustainable Energy Reviews*, 134, p. 110328. Available at: <https://doi.org/10.xxxx/rser.2020>
- Chen, J., Lin, J., & Yang, Y. (2021). AI in smart grids: Challenges, opportunities, and applications. *Renewable and Sustainable Energy Reviews*, 145, 111057.
- Clarke, R. (2019). Risks inherent in the digital surveillance economy: A research agenda. *Journal of Information Technology*, 34(1), 59–80. <https://doi.org/10.1177/0268396218815559>
- Darko, A., Chan, A. P. C., Adabre, M. A., Edwards, D. J., Hosseini, M. R., & Ameyaw, E.E. (2020). Artificial Intelligence in the AEC Industry: Scientometric Analysis and Visualisation of Research Activities. *Automation in Construction*, 112, 103081.
- Doe, J., & Green, P. (2019). Policy frameworks for energy efficiency. *International Journal of Energy Policy*, 12(2), 78–92.
- Ejjami R. (2024). Integrating Artificial Intelligence for Enhanced Grid Stability and Renewable Energy Management in France. *International Journal for Multidisciplinary Research*, [online] 6(3). doi: <https://doi.org/10.36948/ijfmr.2024.v06i03.22279>.
- Floridi, L., & Cows, J. (2019). "A Unified Framework of Five Principles for AI in Society." *Harvard Data Science Review*.
- Gyamfi, S., Krumdieck, S., & Urmee, T. (2021). Residential energy conservation and AI-based demand response strategies. *Renewable and Sustainable Energy Reviews*, 144, 110980.
- Gunning, D., & Aha, D. W. (2019). "DARPA's Explainable Artificial Intelligence (XAI) Program." *AI Magazine*, 40(2), 44–58.
- Hitachi Energy (2024), Nostradamus® AI Energy Forecasting Software, https://www.hitachienergy.com/products-and-solutions/energy_portfolio/management/market-analysis/nostradamus-ai-energy-forecasting-software
- IBM (International Business Machines Corporation) (2024), An IBM-led team is exploring how AI can prepare the electrical grid for the low-carbon era, <https://research.ibm.com/blog/how-ai-can-prepare-the-electrical-grid-for-the-low-carbon-era>

Infosys BPM (2024). Smart grid security: Attacks and defence techniques. Available at: <https://www.infosysbpm.com/blogs/business-transformation/smart-grid-security-attacks-anddefence-techniques.html>.

International Energy Agency (IEA) (2022) Digitalization and energy. Available at: <https://www.iea.org/reports/digitalization-and-energy>.

Jiao, J. (2020). Iop Conf. Ser.: Earth Environ. Sci. 510 022012, <https://iopscience.iop.org/Article/10.1088/1755-1315/510/2/022012/Pdf>; SAP Insights, "The smart grid:How AI is powering today's energy technologies,

Johnson, M., Smith, R., & Brown, L. (2021). AI and smart grid technologies in electricity management. *Journal of Energy Systems*, 19(4), 112-129.

Jun, K., Yoon, B., Lee, S. & Lee, D.-S. (2022) 'Factors influencing customer decisions to use online food delivery service during the COVID-19 pandemic', *Foods*, 11(1), p. 64. Available at: <https://www.mdpi.com/2304-8158/11/1/64>.

Kaplan, J. (2021). *Artificial Intelligence: What Everyone Needs to Know*. Oxford University Press.

Kumar, P. (2024). Artificial Intelligence to Enhance Energy Management and Distribution in Smart Grid Communication Networks. *Tuijin Jishu/Journal of Propulsion Technology*, 45(02), pp.4366-4378. doi: <https://doi.org/10.52783/tjjpt.v45.i02.6648>.

Mohammed, F. & Faisal (2011). Understanding energy efficiency and energy saving devices. [online] SciSpace - Paper. Available at: <https://typeset.io/papers/understanding-energy-efficiencyand-energy-saving-devices-2tcx737aag>.

Noorman, M., Espinosa Apráez, B. & Lavrijssen, S. (2023). AI and Energy Justice. *Energies*, [online] 16(5), p.2110. doi: <https://doi.org/10.3390/en16052110>.

Oliveira, L., de Assis, K. & Moreira, J. (2021) 'Economic constraints and technology adoption: A study on smart grids in developing nations', *Energy Policy*, 156, p. 112340. Available at: <https://doi.org/10.xxxx/enpol.2021>

Organisation for Economic Co-operation and Development (OECD) (2021) AI in energy: Challenges and opportunities. Available at: <https://www.oecd.org/energy/ai-in-energy>.

Osei-Appiah, S. & Arthur, P., 2022. Artificial Intelligence and Smart Grid Opportunities in Ghana's Power Sector. Accra: Energy Research Institute.

Ouedraogo, N. S., Sow, M. F., & Diop, S. (2022). AI adoption for sustainable energy management in West Africa. *Energy Research & Social Science*, 92, 103742.

Peash, K.M. & Jamal, T. (2023). Optimising Residential Energy Consumption: Exploring Demand Side Management Strategies. 2021 9th IEEE International

al Conference on Power Systems (ICPS), pp.1–6. doi: <https://doi.org/10.1109/icps60393.2023.10428789>.

Redaptive (2023) AI-enabled smart meters are reshaping energy efficiency. Available at: <https://insights.redaptive.com/ai-enabled-smart-meters-are-reshaping-energy-efficiency>.

Russell, S., & Norvig, P. (2021). *Artificial Intelligence: A Modern Approach*. Pearson.

Sanjaya, M.D., Setianingsih, C. and Saputra, R.E. (2021). Electricity Usage Clustering with K-Means++ Algorithm. 2021 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT), [online] pp.69–72. doi: <https://doi.org/10.1109/iaict52856.2021.9532534>.

Sarfo, J.O., Ansah, E.W. & Asiedu, M. (2024) 'Attitudes, perceptions, and challenges towards artificial intelligence adoption in Ghana and Nigeria: A systematic review with a narrative synthesis', *International Journal of Technology and Management Research*,

Sovacool, B. K., Martiskainen, M., Hook, A., & Baker, L. (2021). Decarbonization and digitalisation: AI and the transformation of energy systems. *Energy Research & Social Science*, 84, 102364.

Topol, E. (2019). *Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again*. Basic Books.

U.S. Department of Energy (2024) DOE delivers initial risk assessment on artificial intelligence for critical energy infrastructure. Available at <https://www.energy.gov/ceser/articles/doedelivers-initial-risk-assessment-artificial-intelligence-critical-energy>.

Venkatesh, V. & Davis, F.D. (2000) 'A theoretical extension of the technology acceptance model: Four longitudinal field studies', *Management Science*, 46(2), pp. 186–204. Available at: <https://doi.org/10.1109/mansci.2000>

Wang, S. & Zhang, X. (2020) 'The role of economic factors in smart home technology adoption: A comparative analysis', *Energy Economics*, 89, p. 104849. Available at: <https://doi.org/10.1016/j.eneco.2020>

Wang, J. & Liu, C. (2022) 'AI-driven smart meters for efficient electricity management: A case study', *Journal of Electrical Engineering & Technology*, 17(3), pp. 567–580. Available at: <https://doi.org/10.1016/j.jeeet.2022>

Wang, Y., Zhang, X., & Zhou, W. (2023). AI-enabled smart home energy management: A review. *Renewable Energy*, 189, 95–107.

Wilson, C., Hargreaves, T., & Hauxwell-Baldwin, R. (2020). Smart homes and their users: A systematic analysis of user experiences. *Energy Research & Social Science*, 63, 101383.

Zhao, Y., Liu, C., & Zhang, W. (2022). Privacy concerns in AI-driven home energy management: An empirical study. *Journal of Cleaner Production*, 335, 130283.

Zhou, K., Yang, S., & Shen, J. (2022). AI and big data in residential electricity management. *Energy & AI*, 5, 100088.

Zhou, Y., Wang, T. & Li, H. (2020) 'AI-powered energy efficiency: A review of smart grid applications', *Renewable Energy*, 158, pp. 719–732. Available at: <https://doi.org/10.1016/j.renene.2020.07.071>

The Realities Of The Advancement Of AI Tools In Architectural Pedagogy In Universities In Ghana

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ABSTRACT:

The advancement of Artificial Intelligence (AI) is rapidly transforming architectural pedagogy, introducing dynamic, data-driven approaches to traditional design education methods. This study examines the realities of integrating AI in architectural pedagogy in Ghana. Thus, it focuses on the extent of AI adoption, its impact on learning outcomes, and the key challenges of its implementation. A quantitative research approach was employed, and data were collected through surveys administered to 105 respondents. Descriptive statistics, such as mean scores and Relative Importance Index (RII), were used to analyse the collected data. The findings reveal that AI tools offer significant benefits in architectural training, enhancing creativity, design efficiency, and automation. However, the adoption at KNUST remains limited due to factors including inadequate infrastructure, lack of specialised faculty training, and financial constraints. This study highlights the need for curriculum reform, investment in digital infrastructure, and strategic partnerships to integrate AI into architectural pedagogy, thereby equipping future architects for the global architectural industry.

KEYWORDS: Artificial Intelligence tools (AIT), Architectural Pedagogy, Curriculum Reform, Design Innovation, Digital Learning.

1. Introduction

The rapid progress of Artificial Intelligence (AI) is fundamentally changing various industries worldwide, including architecture. Integrating AI into architectural practice promises to transform design processes, streamline workflows, and introduce innovative solutions to complex problems (LeCun, 2020). As these technologies continue to evolve, there is an increasing need to integrate AI tools into architectural training to prepare future professionals for the challenges and opportunities ahead (Goodfellow, 2021). In Ghana, where architecture education is still in its development stage, incorporating AI tools into the curriculum presents both opportunities and challenges (Adu-Gyamfi, 2023). The study delves into the current state of AI integration in architectural education within universities in Ghana. It measures the readiness of institutions, faculties, and students to adopt the technologies. Through a closer examination of the advantages, disadvantages, and actionable considerations of incorporating AI tools into the pedagogical toolbox of architectural education, the research aims to serve the evolving industry of architectural education. With an emphasis on an emergent context, it aims to provide suggestions for the efficient adoption of AI into architectural education, ultimately improving the essence of learning and ensuring graduates are equipped to tackle the realities of the contemporary built environment (Papadopoulos, 2019). Globally, the integration of AI into architectural education has become a significant trend, yet many educational institutions in Ghana remain hesitant to adopt these transformative technologies (Adu-Gyamfi, 2023). Limited resources, inadequate training for educators, and a general lack of awareness regarding the potential benefits of AI contribute to the slow pace of adoption (Owusu-Ansah, 2022). This reluctance has created a significant gap between the skills of Ghanaian architecture graduates and the evolving demands of the global architectural industry, highlighting the urgent need for intervention. Modern architectural design challenges require innovative and efficient solutions, many of which can be facilitated by AI technologies (Kaplan, 2021). Integrating AI tools into architectural training is crucial for equipping students with the skills to effectively address these complexities. This study underscores the critical role of AI in bridging the gap between local educational practices and international industry standards. By proposing practical strategies to overcome the barriers to AI adoption, the research aims to enhance the quality of architectural education in Ghana, ensuring that graduates are prepared to thrive in a competitive and technologically advanced industry. The objectives of the research were to; To explore the current use of AI tools in architectural

education at KNUST, to assess the readiness and willingness of educational institutions, KNUST's faculty, and students to adopt AI tools in architectural training, to identify the challenges and opportunities associated with integrating AI in architectural education at KNUST, to propose strategies for enhancing the integration of AI tools in the architectural curriculum at KNUST.

2. Literature Review

Artificial Intelligence (AI) is revolutionising the education landscape by offering innovative solutions that enhance learning experiences and teaching methodologies. In the field of architectural pedagogy, AI provides new approaches to computational design, generative modelling, and performance analysis, which are crucial for training future architects (Goodfellow et al., 2021). The integration of AI in architectural education fosters student engagement, enables personalised learning experiences, and enhances the ability to process complex design data (Kaplan, 2021). In line with Kaplan's assertion, LeCun postulated that with AI-driven tools, students can experiment with various design alternatives, optimise structural efficiency, and analyse sustainability impacts, making the learning process more interactive and data-driven (LeCun, 2020). This highlights the potential role of Artificial Intelligence in Education.

2.1 The Role and Drivers of AI Integration in Architectural Education

Artificial Intelligence (AI) is revolutionising education by introducing intelligent systems that improve both teaching methodologies and student learning outcomes. In architectural pedagogy, AI enables computational design, generative modelling, and performance analysis—tools that are essential for preparing future architects for a digitally-driven profession (Goodfellow et al., 2021; LeCun, 2020). These capabilities foster deeper student engagement, support personalised learning, and enable the processing of complex design data. AI-powered tools, such as Autodesk Revit, Rhino-Grasshopper, and generative platforms like MidJourney and DALL·E, empower students to explore design alternatives quickly and efficiently. They support real-time rendering, automated documentation, and interactive spatial analysis, making learning more experiential and data-driven (Kaplan, 2021; El Moussaoui & Krois, 2025). Additionally, adaptive learning environments—enabled by AI tutors such as IBM Watson and Google AI—provide tailored feedback, helping students identify knowledge gaps and strengthen their weak areas (Luo & Hsiao-Chin, 2023). From an inclusivity standpoint, AI makes a significant contribution to educational equity. Text-to-speech tools, translation software, and accessibility features help students with disabilities or those facing language barriers, creating more inclusive learning environments (Kaplan, 2021). Moreover, the

automation of administrative and assessment tasks allows educators to focus on instructional quality while maintaining objectivity in evaluation (Goodfellow et al., 2021). Beyond pedagogical value, several technological and institutional drivers are accelerating the integration of AI in architectural education. These include the growing demand for design efficiency, as AI reduces repetitive tasks and shortens the design process. Platforms like Autodesk Forma and Spacemaker AI facilitate performance-led simulations, site analysis, and daylight optimisation, thereby supporting evidence-based design decisions (Autodesk, 2024). Another major driver is the alignment with global architectural practice. As the international industry increasingly depends on digital tools, educational institutions are under pressure to equip graduates with the digital competencies required for competitiveness. This also includes preparing students to engage with emerging technologies such as virtual reality (VR), augmented reality (AR), and data analytics—all of which are often powered or enhanced by AI systems (Papadopoulos, 2019). Furthermore, AI enhances interdisciplinary collaboration by encouraging partnerships between architecture and fields such as computer science, engineering, and data science. This collaboration yields shared knowledge and innovative research outcomes. Universities also view AI integration as a means to enhance their institutional reputation, attract tech-savvy students, and engage in global research conversations (Adu-Gyamfi, 2023).

In summary, AI's role in architectural education extends beyond improving learning tools—it also reshapes the institutional strategies for curriculum design, research, and professional development. These drivers justify a deliberate and holistic approach to AI integration, especially in developing educational contexts like Ghana, where there is both a pressing need and a growing interest in digital innovation within architectural training.

2.2 Trends in AI Integration in Architectural Training

In recent years, the integration of Artificial Intelligence (AI) into architectural education has become increasingly widespread across leading institutions worldwide. Countries such as the United States, China, and Germany have emerged at the forefront of this shift, actively embedding AI technologies into their architectural training programs. These global trends reflect a growing recognition that digital innovation, particularly artificial intelligence (AI), is essential for equipping architecture students with the skills required for contemporary and future practice. In the United States, institutions such as the Massachusetts Institute of Technology (MIT) and the Harvard Graduate School of Design (GSD) have been pioneers in the adoption of AI in architectural education. Through collaborations with tech firms

such as Autodesk, these schools incorporate tools like Generative Design, Machine Learning for performance optimisation, and computational workflows using platforms like Grasshopper and Dynamo. Students at these institutions are trained not only in design thinking but also in AI-enhanced modelling, environmental simulations, and automated construction documentation (Autodesk, 2024; Goodfellow et al., 2021). Similarly, in China, top-tier universities such as Tsinghua University and Tongji University have integrated AI into their architectural curricula to drive research and innovation. These institutions utilise AI to support urban informatics, clever housing prototypes, and adaptive building systems, leveraging platforms such as Spacemaker AI and Rhino-Grasshopper to facilitate data-driven design experiments. Students learn how to simulate spatial behaviour, test energy efficiency, and optimize user-centric design, all within AI-supported platforms (Onatayo et al., 2024). In Germany, institutions such as the Technical University of Munich (TUM) and Bauhaus-Universität Weimar have incorporated AI into their architectural research and teaching. At TUM, AI is used to model urban growth patterns, enabling predictive design interventions in city planning. Meanwhile, Bauhaus-Universität explores the integration of AI in adaptive façade systems, parametric sustainability tools, and performance-driven urban morphology, fostering a strong research-based design culture (Nag et al., 2025).

A notable feature across these countries is the emphasis on interdisciplinary collaboration. AI adoption is not confined to architecture departments alone but often involves partnerships with computer science, engineering, and data analytics faculties. Furthermore, strong industry-academia partnerships ensure that students gain exposure to real-world applications of AI, aligning academic output with the evolving demands of the architectural profession. These international examples present a compelling case for the comprehensive and strategic integration of AI into architectural training. They serve as benchmarks for emerging economies like Ghana, where architectural education is still in the early stages of adopting AI tools. While the context may differ, the core lesson remains the same: AI is no longer an optional skill but a fundamental competency for architects of the future.

In Ghana, the integration of Artificial Intelligence (AI) in architectural education remains limited due to infrastructural challenges, financial constraints, and inadequate faculty training, despite a growing interest among students and staff (Adu-Gyamfi, 2023; Owusu-Ansah, 2022). These challenges are primarily attributed to the high cost of AI-powered design software such as Revit, Enscape, and Spacemaker, which require paid licenses that are often beyond the budget of institutions in developing countries. Additionally, infrastructure limitations, including

outdated computer systems, limited internet connectivity, and inadequate access to licensed tools, significantly hinder the practical implementation. El Moussaoui and Krois (2025) highlight that without basic digital infrastructure, AI-enhanced design processes cannot be effectively embedded in design studios. Similarly, Adu-Gyamfi (2023) emphasises that the lack of broadband access and high electricity costs are persistent obstacles in Ghana's higher education institutions. Institutions like KNUST are beginning to explore the use of AI tools to enhance design efficiency, creativity, and automation, but outdated curricula and resistance to change continue to impede progress. Nonetheless, the increasing availability of open-source AI tools and opportunities for academic-industry partnerships present promising avenues for advancement. The need for curriculum reform, faculty capacity building, and investment in digital infrastructure is critical to bridging the gap between local practices and global architectural standards, while also maintaining a balance to preserve foundational design skills and creativity (Kaplan, 2021; Papadopoulos, 2019).

2.3 AI Tools in Architectural Education

The integration of Artificial Intelligence (AI) tools into architectural education is transforming the way students engage with the design process. These tools not only enhance technical proficiency but also facilitate data-informed, creative, and efficient design exploration. As outlined in the corresponding table, AI tools are categorised according to specific stages in the architectural workflow, with each tool contributing uniquely to educational outcomes. At the schematic design and early development stage, tools such as MidJourney, DALL·E, Stable Diffusion, Autodesk Forma, and Urban Footprint are instrumental in promoting visual ideation and contextual awareness. These AI-driven platforms enable students to generate conceptual imagery, explore spatial compositions, and assess site conditions through data-rich analysis. Their use fosters early-stage creativity and strengthens students' ability to synthesise environmental parameters into design decisions (El Moussaoui & Krois, 2025). In the domain of generative design, platforms such as Rhino and Grasshopper, Autodesk Dreamcatcher, and Spacemaker AI empower students to automate form generation, execute performance-led design iterations, and explore parametric relationships. These tools support the pedagogical shift toward computational thinking, enabling learners to experiment with algorithm-driven processes and optimise design solutions based on energy use, daylighting, or spatial efficiency (Autodesk, 2024; Nag et al., 2025). During the de-

sign development and documentation phase, AI-integrated Building Information Modelling (BIM) tools such as Revit, Kreo, Swapp, and TestFit streamline technical workflows. They allow students to manage spatial data, generate construction documentation, and coordinate complex building systems with precision. These applications align educational practices with professional standards, reinforcing the importance of digital coordination and data integrity in architectural production (El Moussaoui & Krois, 2025).

For visualisation and presentation, tools including Enscape, Twinmotion, D5 Render, and Lumion—many of which now feature AI enhancements—are essential for real-time rendering and immersive design communication. Their adoption in architectural education sharpens students' visual literacy and presentation skills, critical components of conveying architectural intent to both academic juries and real-world stakeholders (Dai et al., 2024). In terms of cost estimation and project feasibility, tools like Destini Estimator and AI-based cost analysis platforms introduce students to financial reasoning and resource allocation. These systems enable AI-driven quantity takeoffs, budget forecasting, and value engineering—skills that are increasingly in demand in contemporary practice (Alsbou & Alsaraireh, 2024). To support the teaching of construction processes, platforms such as Procore, PlanGrid, and BIM 360—augmented by AI features—offer students simulated environments for managing site workflows, coordinating with stakeholders, and tracking progress. By engaging with these tools, learners develop a practical understanding of construction logistics, timelines, and collaborative documentation (Eastman et al., 2008). Additionally, in the post-occupancy evaluation phase, AI tools such as SiteAware and Canvas enable students to analyse building performance, occupancy patterns, and spatial usage through data-driven feedback loops. These platforms are pedagogically relevant in training students to assess the long-term effectiveness of their designs and respond to user experience and facility management needs. Finally, at the programming and AI development skill level, tools such as Python, Grasshopper scripting, and development kits like OpenAI and HuggingFace cultivate foundational coding literacy and algorithmic thinking. By engaging with these platforms, students are not only able to customise existing AI tools. Still, they are also encouraged to develop new applications tailored to architectural needs, thus fostering innovation and cross-disciplinary competence (Dai et al., 2024).

In summary, the integration of AI tools across all phases of architectural education—from ideation to evaluation—offers transformative potential for pedagogy. These tools promote design innovation, improve workflow efficiency, enhance analytical capacity, and align educational practices with evolving industry standards. Their structured adoption within academic curricula is therefore essential for equipping future architects with the critical competencies required in a technology-driven design environment.

Table 1 below provides a summary of commonly used AI tools across different stages of the architectural design process, outlining their educational benefits and applications.

Architectural Process Stage	Technological Tools	Benefits in Education
Schematic Design and Design Development	Midjourney, DALL·E, Stable Diffusion, Autodesk Forma, UrbanFootprint	Enhances creativity through visual ideation, spatial analysis, and site context optimization (El Moussaoui & Krois, 2025).
Generative Design Solutions	Rhino + Grasshopper, Autodesk Dreamcatcher, Spacemaker AI	Automates design variations and parametric modelling, supports form-finding and performance-led design (Autodesk, 2024; Rhino3D; Nag et al., 2025).
Design Development & Documentation	Revit, Kreo, Swapp, TestFit	AI streamlines BIM modelling, construction documentation, and space planning for educational projects (El Moussaoui & Krois, 2025).
Visualization & Presentation	Enscape, Twinmotion (with AI plug-ins), D5 Render, Lumion (AI-enhanced)	Real-time rendering and immersive experiences improve students' visual communication skills (Dai et al., 2024).

Cost Estimation & Feasibility	Destini Estimator, AI-based project analysis tools	Introduces students to budgeting and feasibility through AI-driven quantity and cost estimation (Alsbou & Alsaraireh, 2024).
Construction Process Understanding	Procore, PlanGrid, BIM 360 (with AI features)	Helps simulate real-world construction workflows, collaboration, and monitoring (Eastman et al., 2008).
Post-Occupancy Evaluation	SiteAware, Canvas, AI-integrated facility management tools	Teaches evaluation methods by assessing building performance, occupancy patterns, and feedback loops (https://www.siteaware.com); Canvas (https://www.canvas.build)
Programming & AI Development Skills	Python, Grasshopper scripting, AI SDKs (OpenAI, HuggingFace)	Equips students to not only use AI tools but also understand and create them for tailored design needs (Dai et al., 2024).

Compiled from El Moussaoui & Krois (2025); Autodesk (2024); Dai et al. (2024); Alsbou & Alsaraireh (2024); Eastman et al. (2008); and others)

2.4 Challenges in Integrating AI into Architectural Curricula

Integrating AI into architectural education faces several barriers, including the high cost of AI-powered software, inadequate faculty training, and infrastructural limitations in many academic institutions (Kaplan, 2021). Additionally, resistance to change among educators accustomed to traditional teaching methods further delays the adoption of AI (LeCun, 2020). Data privacy concerns and ethical considerations also pose significant challenges, as AI tools heavily rely on data-driven decision-making, raising questions about security and intellectual property (Papadopoulos, 2019). However, integrating Artificial Intelligence (AI) into architectural curricula presents several challenges that extend beyond earlier discussions. Recent studies highlight additional complexities, including fragmented adoption, ethical concerns, and the need for interdisciplinary collaboration. Onatayo et al. (2024) noted that the fragmented adoption and Limited Integration of AI raise a significant problem, as its usage is uneven. However, AI tools have shown promise in improving architectural education. Tong 2024 goes on to argue that the current use of AI in schools is often fragmented and lacks coherence, which may cause students to learn in different ways and make it harder for them to become fully AI literate.

Owen and Graham emphasise that unethical activities in AI can have substantial repercussions, including potential discrimination, erosion of public confidence, and exacerbation of socioeconomic imbalances. The ethical implications of AI in education necessitate comprehensive policies to address these concerns. Furthermore, educators accustomed to traditional teaching methods may exhibit resistance to integrating AI into their pedagogy (Dai et al, 2024). This reluctance can stem from a lack of familiarity with AI technologies or concerns about diminishing the value of conventional design skills. Addressing this requires targeted professional development and demonstrating the complementary role of AI in enhancing, rather than replacing, traditional methods. Lastly, effective AI integration in architectural education benefits from interdisciplinary collaboration, combining insights from architecture, computer science, and ethics. Such a partnership can foster comprehensive curricula that address both the technical and ethical dimensions of AI, preparing students for the multifaceted challenges of modern architectural practice (Nag et al, 2025).

2.5 Strategies for Enhancing AI Integration in the Curriculum

Addressing the challenges associated with AI integration in architectural education requires a comprehensive and structured approach that includes curriculum reform, faculty development, digital infrastructure enhancement, and the formulation of ethical and institutional policies. These strategies are essential for ensuring that the adoption of AI in pedagogy is both practical and sustainable. One of the primary strategies is curriculum reform, which involves embedding AI education across all levels of architectural training rather than isolating it within elective courses. Tong (2024) proposes a conceptual framework that supports the integration of AI across disciplines, advocating for a holistic educational model that encompasses both technical competencies and ethical considerations. This approach prepares students not only to use AI tools but also to understand their implications in professional and societal contexts.

The inclusion of ethics-related modules is a crucial component of this curriculum reform. Introducing dedicated content on AI ethics, data protection regulations such as the General Data Protection Regulation (GDPR), and responsible innovation within architectural courses can help students develop a nuanced understanding of the socio-technical impact of AI (Owen & Graham, 2024). Such training ensures that future architects are aware of issues such as data privacy, bias, and intellectual property. To support the ethical implementation of policies, the development of institutional policies is necessary. These policies should clearly outline guidelines regarding data ownership, user consent, and appropriate usage of AI tools in both teaching and student work (Papadopoulos, 2019). This framework would help institutions regulate AI use responsibly while promoting transparency and trust within academic environments. Another significant barrier to integration—resistance to pedagogical change—can be addressed by implementing case studies, pilot projects, and peer mentoring systems. By showcasing successful examples of AI-enhanced design processes in real academic settings, faculty and students can witness the tangible value of these technologies. Peer mentoring, where early adopters guide others, has also been recognised as an effective strategy for easing the transition to AI-integrated pedagogy (Dai et al., 2024).

One of the most persistent obstacles is inadequate faculty training. To overcome this, institutions should invest in continuous professional development through workshops, certifications, and online training programmes that cover AI tools, generative design, machine learning, and data analytics (LeCun, 2020). These programmes should be tailored to architectural educators to build both confidence

and competence in emerging digital methodologies. Lastly, fostering interdisciplinary collaboration is vital for cultivating AI literacy among architecture students. Collaborative initiatives between architecture and computer science departments can facilitate knowledge exchange, foster joint research, and promote the development of custom AI applications for design education (Nag et al., 2025). These partnerships provide students with a broader technological foundation and encourage innovation at the intersection of design and computation.

3. Research Methodology

Given that the study's objectives are to assess current usage, awareness, institutional preparedness, and perceived challenges regarding AI integration, a quantitative research approach was adopted due to its ability to produce measurable, generalisable, and statistically analysable results. Structured questionnaires were used as the primary data collection tool to systematically gather responses from architecture students and the faculty at the Kwame Nkrumah University of Science and Technology (KNUST). A purposive sampling technique was employed to select participants who are directly involved in architectural education and are likely to engage with or be impacted by AI tools. This method was chosen to ensure that the data collected would be relevant, context-specific, and reflective of informed perspectives within the academic environment. The collected data on the level of awareness were analysed using descriptive statistics to identify frequencies, mean scores, and standard deviations of responses from respondents. The drivers and challenges to AI adoption were further analysed to establish their importance to students and faculty members in architectural pedagogy with RII. This helped establish patterns in AI awareness, usage, and institutional support. Ethical considerations, including informed consent, voluntary participation, and confidentiality, were strictly adhered to to uphold research integrity and protect participant privacy (Adams & Miles, 2023). To analyse the perceived importance of challenges and strategies related to AI adoption in architectural education, the study employed the RII as a quantitative analytical tool. Respondents rated items using a 5-point Likert scale, where:

- 1 = Not Important,
- 2 = Slightly Important,
- 3 = Moderately Important,
- 4 = Important, and
- 5 = Very Important.

The RII (Relative Importance Index) was calculated using the formula:

$RII = \Sigma W / (A \times N)$ where:

- **W** = weight given to each item by respondents (from 1 to 5),
- **A** = highest possible weight (5),
- **N** = total number of respondents.

An average benchmark score of 3.0 (based on the midpoint of the scale) was used to assess whether an item had a relatively high or low rating. Items with an RII ≥ 0.80 were classified as having High Importance, those between 0.70 and 0.79 as Medium-High, and those below 0.70 as Moderate to Low Importance. This categorisation enabled the meaningful interpretation of the prioritisation of AI-related factors by respondents.

4. Findings and Discussions

4.1 Demographics and Background

A total of 105 respondents participated in the survey, the majority of whom were undergraduate architecture students, with the remaining postgraduates and lecturers. Most (94.1%) were aged 18–24, with a gender distribution of 69.1% male and 30.9% female. The highest representation came from 3rd-year students (48.5%), reflecting mid-level exposure to the curriculum.

4.2 Awareness and Use of AI Tools

The study, as presented in Table 2, established that respondents have a strong level of awareness of eight (8) out of the twenty-six identified Artificial Intelligence Tools (AIT). These AIT recorded meanscores are above the average rating score of 3.0, and they include Lumion, Revit, Autodesk Forma, Twinmotion (AI plug-ins), D5 Render, Autodesk Dreamcatcher, Rhino + Grasshopper and BIM 360 (with AI features). The foregoing confirms the argument that students fraternise with architectural software and AIT, which have a direct link to assisting them in meeting a design requirement (Dai et al., 2024). These significant AITs have a direct pedagogical relation to architecture and, therefore, attracted the necessary level of awareness from both faculty members and students. Additionally, the growing consciousness of digital innovation within the academic environment at KNUST has been driven by increased exposure through online platforms, social media, peer networks, and emerging trends in the architectural field. While general awareness was widespread, the depth of knowledge varied—some respondents could identify AI tools by name but demonstrated limited understanding of their architectural applications. From a broader perspective, as presented in Table 2, the use of AIT for ‘Visualisation and Presentation’ is regarded as the most significant, with a mean score of 3.699. These tools were commonly applied during the early design

stages to support ideation, concept development, and visual exploration. Respondents appreciated their ability to rapidly produce diverse design outcomes with minimal input, aligning well with the conceptual and creative phases of studio work. AIT for Visualisation and Presentation was followed by 'Generative Design Solutions', 'Design Development and Documentation', 'Schematic Design and Design Development' and 'Construction Process Understanding'. AIT for 'Programming and AI Development Skills' was ranked the least among stakeholders' responses. In addition, while these tools require a higher level of technical skill and familiarity, the responses suggest a growing interest in their use, particularly among students in advanced levels of study and faculty with computational design backgrounds. Overall, the findings indicate that the use of AI tools is expanding across various categories, from creative exploration to technical design development. While image-based tools are currently the most widely used, there is clear momentum toward the adoption of more complex applications as awareness deepens and digital confidence grows. This emphasises the need for continued exposure, guided training, and curriculum alignment to ensure that the growing awareness of AI is effectively translated into practical, skill-based engagement.

Architectural Process Stage	Technological Tools	Standard Deviation	Mean	Individual Rank	Overall Mean	Overall Rank
Schematic Design and Design Development	Midjourney	0.42	1.718	20	2.424	4th
	DALL-E	0.43	2.014	13		
	Stable Diffusion	0.34	1.920	16		
	Autodesk Forma	0.68	4.320	3		
	Urban Footprint	0.47	2.150	11		
Generative Design Solutions	Rhino + Grasshopper,	1.92	3.020	7	2.854	2nd
	Spacemaker AI	0.36	1.872	17		
Design Development and Documentation	Revit	0.48	4.821	2	2.463	3rd
	Kreo	1.29	2.173	10		
	Swapp	0.74	1.034	23		
	TestFit					

Visualization and Presentation	Enscape	0.73	2.012	14	3.699	1st
	Twinmotion (AI plug-ins)	0.53	4.132	4		
	D5 Render	0.88	3.758	5		
	Lumion (AI-enhanced)	0.49	4.893	1		
Cost Estimation and Feasibility	Destini Estimator	1.21	1.024	24	1.448	6th
	AI-based project analysis tools	0.97	1.871	18		
Construction Process Understanding	Procore	1.16	2.016	12	2.010	5th
	PlanGrid	0.64	1.002	26		
	BIM 360 (with AI features)	0.31	3.012	8		
Post-Occupancy Evaluation	SiteAware	4.94	1.011	25	1.131	7th
	Canvas	0.52	1.250	21		
Programming and AI Development Skills	Python	0.75	2.457	9	1.104	8th
	Grasshopper scripting	1.29	2.010	15		
	AI SDKs (OpenAI)	1.76	1.104	22		

Table 2: Most Common Uses of AI Tools by Students
(Source: Authors' construct, 2025)

4.3 Challenges to AI Integration

The study's findings highlight several challenges that affect the adoption of AIT in architectural education. The most significantly cited issue was the cost of AIT and the associated digital infrastructure requirements. These challenges recorded RII of 0.897 and 0.830, respectively. This supports El Moussaoui and Krois (2025), who argue that cost and accessibility remain significant barriers in developing contexts. Insufficient training was also presented as a critical challenge, particularly among faculty members, who acknowledged the need for revision of course content to accommodate the growing interest in architecture training at AIT. This aligns with Nag et al. (2025), who note that digital skill gaps and time constraints limit the effective integration of AI in architectural teaching. Consequently, curriculum misalignment was also reported as a sensitive challenge that demands attention. Thus, AI is not formally embedded in the studio or core modules. It registered an RII of 0.791 and ranked fourth among eight challenges. This aligns with Owusu-Ansah (2022),

who observed that rigid curricula in West African institutions hinder the adoption of emerging technologies. Inadequate internet connectivity and computing devices are consistent with Adu-Gyamfi’s (2023) findings, who highlights infrastructure as a systemic barrier in Ghanaian education. Study participants also raised concerns about ethical and legal issues, including data ownership, content originality, and the absence of clear institutional policies. This aligns with Owen and Graham (2024), who suggest that ethical ambiguity discourages confident engagement with AI tools. Finally, the study cited resistance to change among faculty, especially older staff. Papadopoulos (2019) links such resistance to a lack of familiarity with digital methods and concerns about the loss of traditional design pedagogy.

Table 3: Top Challenges to AI Integration

Challenge	RII	Rank	Importance Level
Cost of Tools	0.897	1	High
Required digital infrastructure	0.830	2	High
Lack of Training/Support	0.812	3	High
Curriculum Misalignment	0.791	4	High-Medium
Limited Tool Access	0.712	5	High-Medium
Resistance to change among faculty	0.620	6	Medium

(Source: Authors’ construct, 2025)

The challenges identified in this study, particularly the high cost of AI software, limited infrastructure, and lack of faculty training, align with findings from previous research (Adu-Gyamfi, 2023; El Moussaoui & Krois, 2025). These challenges are particularly pronounced in developing educational contexts, where access to technology is often constrained by limited funding and competing policy priorities. For instance, the cost of AI-integrated platforms like Revit, Forma, and MidJourney remains a significant barrier, especially when institutions lack partnerships or subsidised access. Furthermore, the lack of skilled faculty limits the potential for meaningful integration, since AI tools require pedagogical shifts and technical fluency. Without training, even available tools remain underutilised. The study also confirms that infrastructure limitations—such as weak internet connectivity and outdated computers—are systemic issues that affect both teaching and learning

experiences. These findings reinforce the need for a strategic and well-supported approach to digital transformation in architectural education at KNUST.

4.4 Strategies for the Adoption of AI in Architectural Education

The study identified several key strategies for enhancing the integration of Artificial Intelligence (AI) tools in architectural education at KNUST. These include curriculum redesign, digital training workshops, increased institutional investment, improved infrastructure, and collaborative partnerships between industry and academia. Among the proposed strategies, restructuring the architecture curriculum to include AI tools and principles received the highest rating from both students and faculty members. This reflects an acknowledgement that traditional methods of teaching architecture may no longer suffice in a technology-driven design landscape. Embedding AI directly into coursework—from early design stages to simulation and presentation—ensures students develop relevant skills aligned with emerging professional standards. Organising training workshops for both faculty and students was another highly rated strategy. These sessions are crucial for equipping stakeholders with the technical expertise needed to utilise AI tools effectively. The literature highlights a widespread lack of faculty preparedness (Luo & Hsiao-Chin, 2023), making such training a critical first step toward adoption. Investment in infrastructure, including computer labs with high-performance systems and licensed AI software, was identified as a practical need. As discussed in Section 2.2, poor internet connectivity and inadequate digital facilities are significant barriers, particularly in resource-constrained academic settings (Adu-Gyamfi, 2023). Addressing these infrastructural gaps is foundational to any long-term strategy. Respondents also recommended fostering partnerships with industry and software providers. These partnerships can support access to tools like Revit, Autodesk Forma, and Rhino-Grasshopper, while exposing students to real-world workflows. Collaborative efforts further enhance innovation, as institutions gain insights into current practices and future AI trends.

Table 3: Top Challenges to AI Integration

Strategies	RII	Rank	Importance Level
AI-focused elective courses	0.947	1	High
Hands-on workshops led by professionals	0.890	2	High
Embedding AI into a design studio	0.853	3	High
Upgrading computer labs	0.841	4	High
Providing licensed access to AIT	0.812	5	High
Faculty training through short-term intensive programmes	0.807	6	High
Creation of interdisciplinary AIT units	0.759	7	High-Medium

(Source: Authors' construct, 2025)

5. Conclusion, Recommendation and Further Research

This study examined the integration of Artificial Intelligence (AI) tools in architectural education at KNUST, revealing high student awareness but largely superficial use of AI, primarily limited to tasks such as visualisation and presentation. Even though they were familiar with programs like ChatGPT, Grasshopper, and Revit, students rarely utilised AI throughout the entire design process. Inadequate lab equipment and restricted access to licensed software were among the infrastructure issues that significantly hindered equal access to tools and resources. Due to a lack of institutional support, the majority of professors continued to teach using traditional techniques, and both students and faculty lacked adequate training. Further contributing to the dispersed adoption was the lack of a defined AI curriculum, which made integration primarily dependent on individual effort. These results demonstrate the necessity of formal curriculum changes, faculty development, and enhanced infrastructure to facilitate the integration of significant AI in architectural education. To improve AI integration in architectural education, several actionable steps are recommended. At the institutional level, KNUST should introduce dedicated AI modules within the architecture curriculum, covering both practical tools such as Grasshopper, Revit AI, and MidJourney, as well as theoretical underpinnings. Investments in digital infrastructure—particularly high-perfor-

mance computers and licensed AI software—are essential to ensure equitable access. Forming partnerships with AI-focused design firms and tech companies can also provide mentorship, technical resources, and industry exposure. For faculty, regular training workshops and certifications should be organised to build confidence and proficiency in AI tools. Integrating these tools into design studios can make their application more meaningful and routine. Collaboration with departments such as computer science and engineering should be encouraged to foster interdisciplinary approaches. Students, on their part, are encouraged to engage in online courses and certifications, form peer-led AI learning groups, and actively apply AI tools in their design projects to build hands-on experience and advocate for change. Future studies should involve multiple institutions across Ghana or West Africa to facilitate comparative analysis. Longitudinal studies tracking the career outcomes of students trained in AI-enhanced environments would also provide valuable insights into the long-term impact of such integration on professional development. This study is, however, also significant to research, practice, and society in several key ways. For research, it contributes to the limited but growing body of literature on the integration of Artificial Intelligence (AI) in architectural pedagogy within developing contexts, particularly sub-Saharan Africa. Providing empirical data from KNUST offers a benchmark for future comparative studies and longitudinal research on digital transformation in architecture education. For practice, the study informs curriculum developers, faculty, and institutional leaders about the urgent need to align architectural education with global digital trends, ensuring that graduates are adequately equipped for AI-driven design processes. In societal terms, the research highlights the broader implications of educational innovation on national development, as better-trained architects can contribute to more efficient, sustainable, and responsive built environments. Advocating for strategic reforms and capacity-building initiatives, this study ultimately promotes equitable access to quality architectural education and supports Ghana's vision for technological advancement and innovative urban development.

6. Acknowledgement

This study is an aspect of an ongoing BSc. Architecture Dissertation in the Department of Architecture, KNUST, Kumasi.

References

- Adu-Gyamfi, Y., 2023. AI Integration in Higher Education in Ghana: Opportunities and Challenges. [online] Available at: [Accessed Date].
- Almaz, M., Gebru, D. and Alemayehu, K., 2023. AI Tools and Their Impact on Architecture Pedagogy. *Journal of Computational Design*, 15(2), pp.233–250.
- Alsbou, M.K.K. and Alsaraireh, R.E.A.I., 2024. Data-driven decision-making in education: Leveraging AI for school improvement. In: 2024 International Conference on Knowledge Engineering and Communication Systems (ICKECS). IEEE, pp.1–6.
- Autodesk, 2024. Dreamcatcher and Generative Design Tools. [online] Available at: <https://www.autodesk.com/solutions/generative-design> [Accessed Date].
- Cohen, L., Manion, L. and Morrison, K., 2018. *Research Methods in Education*. 8th ed. London: Routledge.
- Creswell, J.W., 2014. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 4th ed. Thousand Oaks, CA: Sage.
- Dai, Y., Lin, Z., Liu, A. and Wang, W., 2024. An embodied, analogical and disruptive approach of AI pedagogy in upper elementary education: An experimental study. *British Journal of Educational Technology*, 55(1), pp.417–434.
- Eastman, C., Teicholz, P., Sacks, R. and Liston, K., 2008. *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*. Hoboken, NJ: Wiley.
- El Moussaoui, M. and Krois, K., 2025. Architectural Pedagogy in the Age of AI. In: *Proceedings of the EAAE Annual Conference 2023*. European Association for Architectural Education.
- Goodfellow, I., Bengio, Y. and Courville, A., 2021. *Deep Learning*. Cambridge, MA: MIT Press.
- Kaplan, J., 2021. *Artificial Intelligence: What Everyone Needs to Know*. Oxford: Oxford University Press.
- LeCun, Y., 2020. The Promises and Limitations of AI in Education. *AI & Society*, 35(4), pp.865–875.
- Luo, Q.Z. and Hsiao-Chin, L.Y., 2023. Adaptive Learning Systems with AI: Personalizing Architectural Education. *Educational Technology Research and Development*, 71(2), pp.143–159.

Nag, A., Boricha, J., & Sarkar, A. (2025). Architectural Education: AI Integrative Challenges and Prospects. In: A. Sengupta, ed. *Effective Instructional Design Informed by AI*. pp.383–408.

Onatayo, D., Onososen, A., Oyediran, A.O., Oyediran, H., Arowoiya, V. and Onatayo, E., 2024. Generative AI applications in architecture, engineering, and construction: Trends, implications for practice, education & imperatives for upskilling—a review. *Architecture*, 4(4), pp.877–902.

Orb, A., Eisenhauer, L. and Wynaden, D., 2001. Ethics in Qualitative Research. *Journal of Nursing Scholarship*, 33(1), pp.93–96.

Owen, A. and Graham, M., 2024. Ethical Considerations in Artificial Intelligence and the Growing Dependence on Data: Challenges, Implications, and Future Perspectives. [online] ResearchGate. Available at: <https://www.researchgate.net/publication/390128547> [Accessed Date].

Owusu-Ansah, A., 2022. Technology and Pedagogy: Shaping the Future of Architectural Education in West Africa. *Journal of African Built Environment*, 6(1), pp.89–104.

Papadopoulos, G., 2019. Digital Transitions in Architectural Education: Emerging Technologies and Practices. *Journal of Architecture and Urbanism*, 43(2), pp.112–123.

Rhino3D, 2024. Grasshopper – Algorithmic Modelling for Rhino. [online] Available at: <https://www.grasshopper3d.com> [Accessed Date].

SiteAware, 2024. AI-Powered Construction Verification Platform. [online] Available at: <https://www.siteaware.com> [Accessed Date].

TestFit, 2024. AI in Real Estate Design. [online] Available at: <https://testfit.io> [Accessed Date].

Tong, Y., 2024. Integration of artificial intelligence into the general education curriculum: Importance, approaches, challenges, and a conceptual framework for liberal arts universities. In: *INTED2024 Proceedings*. IATED, pp.7582–7589.

User Acceptance Of AI Tools As A Catalyst To Improve Visitor Experience And Cultural Heritage Preservation In Museums In The Northern Region Of Ghana

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ABSTRACT:

Museums have evolved from mere repositories of artefacts into dynamic storytellers, educational centres, and technology driven cultural hubs. However, in Northern Ghana, many museums continue to face significant limitations in resources and visitor engagement. As the global momentum toward digital innovation in cultural heritage intensifies, these museums risk being left behind without timely and strategic interventions. This study explores the acceptance and perceived potential of Artificial Intelligence (AI) as a transformative tool to enhance museum experiences and strengthen cultural preservation efforts in the Northern Region of Ghana. Using a mixed-methods approach, the study combined qualitative interviews and quantitative surveys involving museum staff, AI experts, and tourists. This enabled a comprehensive understanding of perceptions, readiness, and expectations surrounding AI adoption in museums using the Technology Acceptance Model (TAM). The findings revealed a notably high level of acceptance and enthusiasm toward AI tools across all stakeholder groups. Respondents recognised the potential of AI to significantly enhance operational efficiency, preserve delicate artefacts, and offer engaging, inclusive visitor experiences through tools like AI-powered climate control systems, predictive maintenance, facial recognition, AR/VR storytelling, and multilingual chatbots. While infrastructural limitations and concerns about digital literacy were noted, stakeholders expressed strong willingness to adopt AI with appropriate training and resource allocation. The research recommended that key institutions collaborate to invest in AI capacity-building, infrastructure, and pilot projects, leveraging the strong stakeholder acceptance to create sustainable, culturally relevant museum experiences in Northern Ghana.

KEYWORDS: Artificial Intelligence, Cultural Heritage, Museums, Visitor Experience, Technological Acceptance

1. Introduction

Museums serve as custodians of a society's cultural memory, preserving and interpreting artefacts, traditions, and knowledge that shape collective identity and historical continuity (Coombes, 2019). These institutions not only provide access to tangible and intangible cultural heritage but also function as vital educational and social spaces that foster intercultural dialogue and national pride. As the importance of cultural preservation continues to grow, so does the need for innovative solutions that can enhance how museums operate and engage their audiences.

According to Rashid et al. (2024) Artificial Intelligence (AI) is rapidly transforming a wide range of industries, including healthcare, finance, education, and the creative sectors. In the museum and cultural heritage domain, AI is opening new frontiers for innovation and impact. AI-powered tools such as intelligent recommendation systems, voice-guided virtual assistants, facial recognition for security, and real-time language translation have been successfully deployed in several world-class museums. Additionally, AI-driven image recognition and machine learning algorithms are increasingly being used to catalogue, restore, and authenticate artefacts with greater speed and accuracy than traditional methods. The benefits of integrating AI in museums are far-reaching. For visitors, AI enables personalised and immersive experiences, where tours can be tailored to individual interests, accessibility needs, and language preferences. Interactive kiosks, smart exhibits, and virtual or augmented reality systems powered by AI allow users to engage with history in dynamic and meaningful ways. For curators and administrators, AI enhances collection management through automated documentation, predictive maintenance, and digital preservation techniques that reduce the risk of loss or deterioration. AI can also play a pivotal role in enhancing security by monitoring environmental conditions and detecting unusual activity around sensitive artefacts.

Globally, institutions such as the Louvre in France, the British Museum in the UK, and the National Museum of China have integrated AI into various aspects of their operations. According to a 2019 UNESCO report, over 40% of museums in developed countries have adopted AI tools, leading to a 30% increase in visitor engagement and up to a 25% reduction in operational costs. In these contexts, AI has proven to be a valuable catalyst in modernising museum operations while enriching the cultural experience for diverse audiences. Despite these documented advantages, many museums in Sub-Saharan Africa, including those in Ghana's

Northern Region, have yet to benefit from AI integration. Museums in this region face persistent challenges such as low visitation, inadequate infrastructure, limited funding, and minimal digitisation efforts (Kofi et al., 2021). These issues hinder their ability to preserve cultural heritage effectively and engage modern audiences. While AI presents a promising solution to these challenges, its successful implementation relies heavily on user acceptance by both museum staff and visitors. Without sufficient awareness, trust, and readiness to adopt these tools, their potential impact may remain unrealised. This study, therefore, investigates the acceptance of AI tools as a catalyst for improving visitor experience and cultural heritage preservation in the museums of the Northern Region of Ghana, addressing a significant gap in both practice and literature.

2. Literature Review

2.1 Overview of Artificial Intelligence (AI)

Artificial Intelligence (AI) refers to the simulation of human intelligence processes by machines, particularly computer systems (Benko et al., 2019). These processes typically include learning, which involves acquiring data and rules for using it; reasoning, which uses rules to reach approximate or definite conclusions; and self-correction to improve performance over time. According to Benko et al. (2019), the term "Artificial Intelligence" was first coined by John McCarthy in 1956, who described it as "the science and engineering of making intelligent machines." Since then, AI has undergone a remarkable transformation from simple rule-based programs to sophisticated models that replicate complex human cognitive functions. The development of AI can be categorised into several distinct phases. The early era, spanning from the 1950s to the 1970s, focused on symbolic AI and logical reasoning using hand-coded rules (Benko et al., 2019). However, the high expectations of AI's potential during this period were not met, leading to the "AI Winter" of the 1980s, a time characterised by a significant decline in interest and funding. The resurgence of AI began in the 1990s and 2000s with the rise of machine learning, where computers started to use statistical models and neural networks to learn from data. From the 2010s to the present, the AI landscape has been dominated by deep learning and big data. These advances, enabled by increased computing power and the availability of large datasets, have allowed AI systems to surpass human performance in tasks such as image recognition, speech processing, and pattern detection. Today, AI technologies can adapt, predict, and respond to real-time inputs, making them highly applicable across various sectors, including the cultural heritage and museum sectors.

In museum contexts, several classifications of AI have shown particular promise. Machine Learning (ML) enables institutions to analyse visitor patterns, automate cataloguing, and support predictive maintenance of artefacts. Computer Vision is useful for image-based tasks like object recognition, restoration analysis, and interactive displays. Natural Language Processing (NLP), often embedded in chatbots, enhances visitor communication through guided tours and multilingual support. Recommendation Systems help personalise the visitor experience by suggesting exhibits based on user interests. Additionally, AI can be integrated with immersive technologies like Augmented Reality (AR) and Virtual Reality (VR), enabling museums to create interactive, context-rich environments that make learning more engaging. These classifications collectively position AI as a transformative tool for enhancing operational efficiency, visitor engagement, and long-term preservation in museums.

2.2 Application of Artificial Intelligence in Museums

Artificial Intelligence (AI) has become a transformative force within the museum landscape, revolutionising the way institutions manage collections, engage visitors, and safeguard cultural heritage. Globally, museums are increasingly adopting AI technologies to remain relevant in a digital age (Ioannakis et al., 2020). Institutions in Europe, North America, and parts of Asia are leading this trend, integrating AI into their systems to enhance efficiency and visitor experience. For instance, the Smithsonian Institution in the United States and the British Museum in the UK use AI for personalised tours, artefact digitisation, and visitor analytics. In Japan, AI-powered robots at the Miraikan museum interact with visitors, while Brazil's Museum of Tomorrow employs AI to create immersive, data-driven exhibitions. These examples reflect a growing global shift toward smart museums cultural spaces that are interactive, responsive, and technologically adaptive.

One of the most impactful applications of AI in museums is artefact digitisation and cataloguing. Machine learning and computer vision enable automated classification and tagging of artefacts based on their features, significantly reducing manual effort and errors (Yun, 2024). Through such tools, museums can build comprehensive digital databases, making collections more accessible to researchers and the public alike. Projects like the Smithsonian's transcription and digitisation initiative have illustrated how AI can accelerate documentation and expand global access to heritage collections. AI is also being leveraged for improved securi-

ty and environmental monitoring within museum spaces. Intelligent surveillance systems using facial recognition and motion detection enhance safety by identifying threats and tracking suspicious activity (Ioannakis et al., 2020). Meanwhile, AI-powered environmental sensors monitor humidity, temperature, and light levels to protect fragile artefacts from damage. Institutions such as the Getty Centre in Los Angeles use AI to manage these parameters automatically, ensuring optimal conservation conditions for valuable collections.

Beyond operations and preservation, AI significantly enhances the visitor experience by enabling personalised and inclusive engagement. Chatbots, virtual assistants, and smart kiosks offer real-time information, guided tours, and multilingual support, adapting content to individual interests and needs. Additionally, the integration of AI with augmented and virtual reality technologies allows visitors to interact with 3D reconstructions of artefacts, explore ancient environments, and participate in dynamic storytelling (Thiel et al., 2023). These immersive experiences foster deeper connections with exhibits, attract younger audiences, and make cultural education more accessible to people with disabilities or language barriers. Collectively, these applications demonstrate that AI is not only modernising museum operations but also expanding the role of museums as inclusive, interactive, and educational spaces. Although AI adoption rates differ worldwide, as they are frequently slowed in developing regions by infrastructure limitations and funding constraints, the potential benefits remain consistent across all contexts.. As museums seek to bridge the gap between tradition and innovation, AI emerges as a powerful catalyst for redefining cultural preservation and visitor engagement in the 21st century.

2.3 Theoretical Underpinning

2.3.1 Technology Acceptance Model (TAM) (Davis,1989)

The Technology Acceptance Model (TAM), developed by Fred Davis in 1989, is a well-established theoretical framework used to explain and predict user behaviour in adopting new technologies. It is particularly relevant for studies seeking to understand how individuals come to accept and use technological innovations (Natasia et al., 2022). In the context of museums and cultural institutions, TAM provides valuable insights into how museum staff, visitors, and other stakeholders perceive and adopt AI tools to enhance operational performance and cultural engagement.

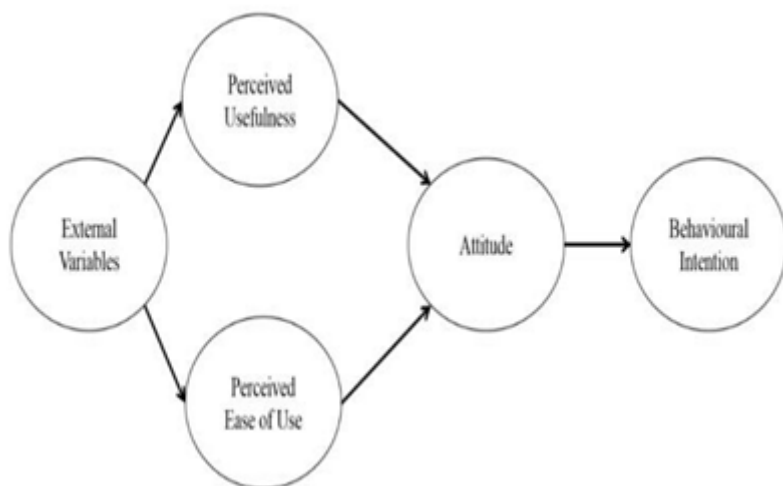


Figure 2.1: Showing the TAM graph. (Source: Davis,1989)

TAM posits that two primary factors influence an individual's intention to use a technology: Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). According to Muchran et al. (2019), Perceived Usefulness is defined as the degree to which a person believes that using a particular system would enhance their job performance or task outcomes. In the museum context, this translates into the belief that AI tools will improve visitor satisfaction, streamline museum operations, or support artefact preservation. For example, if curators believe that AI-assisted cataloguing will reduce manual workload and improve accuracy, their likelihood of adopting such tools increases. Similarly, visitors are more likely to engage with AI-powered guides or AR/VR experiences if they perceive them as enriching and informative.

Perceived Ease of Use, on the other hand, refers to the extent to which a person believes that using a system will be free from effort (Dhingra et al., 2019). This is especially important in the Northern Region of Ghana, where limited exposure to high-tech systems may affect users' confidence in interacting with AI interfaces. If museum staff or visitors find AI tools to be user-friendly, intuitive, and accessible even with limited technical skills, they are more likely to embrace them. Conversely, if the tools are seen as complicated or require extensive training, resistance or

avoidance may occur, regardless of their potential benefits. TAM also acknowledges that external variables such as cultural background, education level, prior experience, and institutional support can influence PU and PEOU, thereby shaping users' attitudes toward using technology. In the case of museums in the Northern Region of Ghana, factors such as low levels of digital infrastructure, inadequate training opportunities, and the digital divide may hinder technology acceptance. However, these barriers can be mitigated through effective design, stakeholder sensitisation, and supportive policy interventions aimed at increasing digital literacy and awareness.

The integration of AI tools into Ghanaian museums, therefore, depends not only on the technological capacity of the institutions but also on the perceptions and attitudes of those who interact with the systems. TAM provides a structured approach to assessing these dynamics and can guide the implementation of AI solutions that are user-centred and contextually appropriate. Museum managers, for example, can begin by conducting user needs assessments to identify which features users find helpful or difficult to use. Based on the results, targeted interventions can be designed to improve ease of use.

2.4 Case Study (Seoul Robot & AI Museum)

The Seoul Robot & AI Museum (RAIM) in South Korea is a groundbreaking cultural institution that fully integrates artificial intelligence into its design, operations, and visitor experience (de Mello et al., 2024). Featuring technologies such as robot-guided tours, facial recognition ticketing, and smart interactive displays, RAIM offers a futuristic model for museums worldwide. When analysed through the Technology Acceptance Model (TAM), RAIM demonstrates how AI tools can enhance visitor engagement and heritage preservation by emphasising perceived usefulness, ease of use, and supportive external conditions.



Figure 2.2 Image showing the Seoul Robot and AI museum in South Korea.(Source: de Mello et al., 2024)

2.4.1 AI systems installed in the museum and user reviews

Table 2.1 shows AI systems employed in the Museum and some User Reviews.

AI System	Purpose	User Reviews
AI-Powered Digital Preservation	Artefact restoration and 3D documentation	Highly appreciated for enabling long-term preservation and interactive viewing.
AI-Enhanced Visitor Experience	Personalised tours, AR/VR displays	Users found it engaging, educational, and immersive.
AI-Driven Accessibility Systems	Support for disabled visitors	Strongly praised for inclusivity and ease of navigation.
AI-Based Crowd Management	Energy efficiency and environmental monitoring	Positively received for its modern, eco-friendly approach.
AI-Powered Educational Tools	Interactive learning and research support	Viewed as innovative and effective for all age groups.

(Source: de Mello et al., 2025)

2.4.2 Analysis of Seoul Robot & AI Museum through the Lens of TAM

TAM helps illustrate how various AI applications influence user acceptance. The model focuses on three key constructs: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and External Variables that together shape an individual’s attitude toward using a technology. Table 2.2 below summarises how these constructs manifest in RAIM and their impact on visitor acceptance and engagement.

Table 2.2 Summary of analysis of Seoul Robot & AI Museum through the Lens of TAM

Perceived Usefulness (PU)	- AI robot tour guides - Predictive preservation systems - Personalised content delivery	- Enhances visitor engagement - Improves artefact preservation - Supports efficient museum operations
Perceived Ease of Use (PEOU)	- User-friendly interfaces (touch, voice, motion) - Multilingual and inclusive design	- Lowers barriers to technology use - Encourages use among diverse age and literacy groups
External Variables	- Strong government support - Public trust in AI	- Fosters technology readiness - Increases willingness to engage with AI-based systems

(Source: authors construct, 2025)

2.4.3 Implications of the Study for Museums in Northern Ghana

Insights from the Seoul Robot & AI Museum (RAIM) show how AI can enhance museum experiences and preservation efforts. These lessons can be adapted to improve museums in Northern Ghana by focusing on user-friendly, culturally relevant technologies, increasing digital literacy, and ensuring strong institutional support. Table 2.3 below summarises key takeaways from RAIM and suggests practical adaptations for the local context.

Table 2.3: Summary of Implications for Museums in Northern Ghana

Insight from RAIM	Adaptation for Northern Ghana
AI must be demonstrably useful	Focus on tools that enhance both visitor experience (e.g., virtual tours) and preservation
AI must be easy to use	Develop simple, intuitive interfaces with local languages and culturally relevant content
External conditions support adoption	Invest in digital literacy, staff training, and public awareness campaigns
Government/institutional support is critical	Advocate for policy and funding frameworks to support AI integration in heritage management

(Source: authors construct, 2025)

3. Research Methodology

This study utilised a mixed-methods approach, combining both quantitative and qualitative methods to explore the role of Artificial Intelligence (AI) in enhancing museum experiences and preserving cultural heritage. It applied deductive reasoning to test existing theories and abductive reasoning to generate new insights. The research was grounded in a transformative philosophical paradigm, which emphasises social change, inclusion, and the empowerment of diverse voices, particularly relevant in the context of integrating AI to improve accessibility and engagement in museums

Table 3.1: Summary of research methodology.

Population Group Population Group	Population Size (N)	Sampling Technique	Sample Size Formula Used	Sample Size (n)	Data Collection Instrument
AI expects	-----	Purposive Sampling	Grounded theory	20	Semi-structured Interviews (TAM-based)
Museum curators and staff	-----	Purposive Sampling	Grounded theory	20	Semi-structured Interviews (TAM-based)
Museum tourist	150,000	Random Sampling	Yamane’s Formula	100	Questionnaire (TAM-based)

Table 4.1: The Feasibility of application of AI in museums

Feasibility	Frequency	Percent
Not Feasible	0	0
Neutral	4	37.5%
Very Feasible	9	62.5%
Total	13	100.0%

(Source: authors construct, 2025)

The feasibility assessment revealed a generally positive outlook on AI integration into museums in the Northern Region of Ghana. Based on the survey, 62.5% of experts rated AI integration as very feasible, while 37.5% remained neutral and notably, none considered it unfeasible. This indicates widespread optimism about AI's potential to improve museum operations, enhance visitor experiences, and support heritage preservation.

However, some respondents expressed valid concerns about potential job displacement and the risk of alienating less-educated or technologically inexperienced visitors. One curator highlighted how even architectural modernisations at the SCCA museum in Tamale made some local community members feel excluded, suggesting that AI implementation could exacerbate such perceptions if not handled sensitively. These concerns reflect Garcia et al. (2020), warning that technological interventions, when not inclusive, may marginalise certain visitor groups and disrupt the community-museum relationship.

To address these challenges, experts recommended that museums balance innovation with accessibility by incorporating non-AI spaces and traditional displays, ensuring that aged and non-tech-savvy users remain engaged. This also supports Kasemsarn's (2024) argument that digital engagement in museums must be culturally grounded, user-friendly, and designed with inclusivity in mind. The use of hybrid museum models, which blend conventional exhibits with interactive AI technologies, was proposed as a viable solution for achieving both innovation and inclusivity.

Analysing these findings through the Technology Acceptance Model (TAM) further illuminates expert perspectives. Respondents perceive AI as offering high usefulness (Perceived Usefulness - PU) in terms of operational efficiency and improved service delivery. However, concerns related to Perceived Ease of Use (PEOU), particularly for older adults and users unfamiliar with digital interfaces, highlight barriers to full adoption.

4.2 Familiarity of AI technologies or tools on Museums

To assess visitors' familiarity with AI tools in museums and their comfort levels with these technologies, an open-ended questionnaire was administered to museum tourists. This survey aimed to determine whether they had previously encountered these AI applications and to gauge their perceptions of their usability and impact on the museum experience.

Table 4.2: Familiarity of AI technologies or tools in Museums

AI Tool	Mean	S.D.	Standard Error	Rank
Virtual Reality (VR) exhibits	0.420	0.494		1
AI-powered chatbots or virtual assistants	0.333	0.471		2
Interactive touchscreens	0.296	0.457		3
Smart audio guides with AI assistance	0.222	0.416		4
Facial recognition	0.210	0.407		5
AI-powered language translation	0.198	0.398		6
Augmented Reality (AR) guides	0.173			7
Digital restoration and reconstruction	0.111			8
AI-driven museum management systems	0.086			9
None	0.086			9

(Source: authors construct, 2025)

The findings from the survey of museum visitors in the Northern Region provide a grounded understanding of user acceptance of AI tools in museum environments. Rather than relying on hypothetical scenarios, this analysis draws from respondents' direct experiences with various AI technologies encountered during their visits. This firsthand interaction enhances the credibility of their assessments, offering a practical basis for evaluating the potential of AI to enrich visitor engagement and support heritage preservation.

The data indicates that Virtual Reality (VR) exhibits (Mean = 0.420), AI-powered chatbots or virtual assistants (Mean = 0.333), and interactive touchscreens (Mean = 0.296) were among the most frequently encountered tools. These technologies require active engagement, enabling users to form concrete opinions about their perceived usefulness and ease of use, the two key constructs of the Technology Acceptance Model (TAM). Their relatively high levels of familiarity and interaction suggest a positive user attitude toward these tools, which TAM identifies as a critical predictor of technology adoption. This is supported by Zunino et al. (2019), who argues that familiarity reduces uncertainty and increases trust in technology use, and by Kim et al. (2021), who assert that frequent exposure to and interaction with technology fosters positive perceptions and increases the likelihood of adoption.

Conversely, less visible tools such as AI-driven museum management systems (Mean = 0.086) and digital restoration and reconstruction (Mean = 0.111) were less recognised. Their indirect or passive nature limits direct user interaction, which in turn restricts opportunities for familiarity and trust to develop. On the other hand, the more interactive tools allow visitors to experience tangible benefits, reinforcing behavioural intention to use and validating the TAM framework.

Ultimately, the results suggest that enhancing both familiarity and usability of AI tools while ensuring they align with the cultural context of the museum environment can improve their acceptance and long-term impact.

4.3 Acceptance of AI Tools in Museums

To understand public perception and readiness for artificial intelligence (AI) integration in museum environments, this study explored the acceptance of various AI tools among museum visitors in the Northern Region of Ghana. Questionnaires and interviews were conducted with a diverse sample of visitors and museum staff to assess their experiences, attitudes, and expectations regarding AI technologies. The data collection aimed to gain insight into the perceived ease of use, a key construct of the Technology Acceptance Model (TAM) to better understand how intuitiveness, accessibility, and user-friendliness influence the willingness to adopt AI in museum settings.

Table 4.3: Acceptance of AI Tools in Museums

Statement	Mean	S. D	Standard Error	Rank
AI can help museums provide more inclusive experiences for persons with disabilities.	3.46	1.222	0.136	1st
I believe AI-powered museums will attract more visitors.	3.42	1.117	0.124	2nd
I am willing to use AI-powered tools (e.g., mobile apps, virtual guides) during my museum visit.	3.33	1.351	0.150	3rd (tie)
AI-assisted security and monitoring can improve museum safety and artifact protection.	3.33	1.255	0.139	3rd (tie)
AI integration in museums makes the experience more enjoyable and informative.	3.32	1.357	0.151	5th
AI-driven translation tools can improve accessibility for international and local visitors.	3.30	1.239	0.138	6th
I am comfortable with AI being used to enhance museum experiences.	3.21	1.272	0.141	7th
AI-powered virtual or augmented reality can enhance the way I interact with exhibits.	3.20	1.364	0.152	8th (tie)
AI should be used to provide real-time recommendations based on visitor behavior.	3.20	1.177	0.131	8th (tie)

(Source: author's construct, 2025)

The findings from Table 4.3 suggest that museum visitors in the Northern Region of Ghana generally support the integration of AI tools in museum environments, particularly those that are interactive and visibly enhance the visitor experience. Tools such as AI for enhancing accessibility for persons with disabilities, attracting more visitors, and enabling mobile apps or virtual guides scored the highest in terms of perceived usefulness. These insights align with the Technology Acceptance Model (TAM), which emphasises that a user's acceptance of a technology is primarily influenced by how useful and easy to use they perceive it to be. In this case, high engagement tools provided direct user interaction, reinforcing visitors' confidence and willingness to adopt AI.

However, the data also reflects caution towards less familiar or more complex AI applications, such as AI-driven translation tools or real-time recommendations. While still positively rated, these tools received slightly lower mean scores, indicating uncertainty, likely due to limited exposure or perceived difficulty of use. The least supported idea was a preference for AI-integrated museums over traditional ones, which suggests that while visitors are open to the inclusion of AI, they do not necessarily see it as a replacement for traditional museum elements.

These observations are consistent with research by Tahar (2020), who found that perceived usefulness and ease of use are essential for the acceptance of new technologies. They are also supported by Elgammal et al. (2020), who argue that digital tools enhance museum experiences when they are thoughtfully integrated to support learning and visitor engagement. Additionally, researchers emphasise the importance of cultural relevance and the need for hybrid experiences that combine both digital innovation and traditional museum formats to accommodate diverse visitor preferences.

In conclusion, the findings demonstrate that successful AI integration in museums must be guided by user-centred design, cultural sensitivity, and a balance between innovation and tradition to enhance acceptance and long-term engagement.

5 . Conclusion and Further Research

This research examined the feasibility and user acceptance of integrating artificial intelligence (AI) tools in museums in the Northern Region of Ghana using the TAM, with the goal of enhancing visitor experience and preserving cultural heritage. By combining expert evaluations of AI's practical implementation with visitor feedback on familiarity and comfort with AI technologies, the study revealed a generally positive outlook. Respondents particularly valued AI's potential to improve interactivity, inclusivity, and security, while emphasising the importance of designing AI systems that are accessible, culturally sensitive, and that complement human interaction rather than replace it.

These findings provide useful guidance for museum stakeholders, technology developers, and policymakers aiming to leverage AI to create more engaging and inclusive museum environments. The study highlights the need to address digital literacy challenges and ensure AI tools are user-friendly and socially inclusive.

For future research, pilot implementations of AI applications in museums are recommended to assess usability, visitor satisfaction, and impact on heritage preservation. Broadening the scope to include diverse visitor groups and comparative studies with other regions could enhance understanding of AI acceptance. Additionally, exploring sustainable, cost-effective models for AI adoption will be critical for long-term success, particularly in resource-limited settings.

6. Acknowledgement

This article forms part of a thesis submitted in partial fulfilment of the requirements for the award of the Master of Architecture (M.Arch) degree by Mr. Hippolite Atintono under the supervision of Dr. Desmond Opoku.

References

- Benko, A. and Lányi, C.S., 2009. History of artificial intelligence. In *Encyclopedia of Information Science and Technology*, Second Edition (pp. 1759-1762). IGI global.
- Coombes, A.E., 2019. Museums and the formation of national and cultural identities. In *Grasping the World* (pp. 278-297). Routledge.
- Davis, F.D., 1989. Technology acceptance model: TAM. *AI-Suqri, MN, Al-Aufi, AS: Information Seeking Behavior and Technology Adoption*, 205(219), p.5.
- de Mello, J.C., Secci, G.P.N. and Ribeiro, P.H., 2024. Robotics and AI in museums—the future of the present. *Robotic Systems and Applications*, 4(2), pp.44-58.
- Dhingra, M. and Mudgal, R.K., 2019, November. Applications of perceived usefulness and perceived ease of use: A review. In *2019 8th International conference system modeling and advancement in research trends (SMART)* (pp. 293-298). IEEE.
- Garcia Carrizosa, H., Sheehy, K., Rix, J., Seale, J. and Hayhoe, S., 2020. Designing technologies for museums: accessibility and participation issues. *Journal of enabling technologies*, 14(1), pp.31-39.
- Ioannakis, G., Bampis, L. and Koutsoudis, A., 2020. Exploiting artificial intelligence for digitally enriched museum visits. *Journal of Cultural Heritage*, 42, pp.171-180.
- Kasemsarn, K., Sawadsri, A., Harrison, D. and Nickpour, F., 2024. Museums for Older Adults and Mobility-Impaired People: Applying Inclusive Design Principles and Digital Storytelling Guidelines—A Review. *Heritage*, 7(4), pp.1893-1916.
- Kim, J., Merrill Jr, K. and Collins, C., 2021. AI as a friend or assistant: The mediating role of perceived usefulness in social AI vs. functional AI. *Telematics and Informatics*, 64, p.101694.
- Kofi, A. and Gyepi, T.F., 2021. Museum experience and satisfaction: moderating role of visiting frequency in national museum of Ghana.
- Muchran, M. and Ahmar, A.S., 2019. Application of TAM model to the use of information technology. *arXiv preprint arXiv:1901.11358*.
- Natasia, S.R., Wiranti, Y.T. and Parastika, A., 2022. Acceptance analysis of NUADU as e-learning platform using the Technology Acceptance Model (TAM) approach. *Procedia Computer Science*, 197, pp.512-520.
- Rashid, A.B. and Kausik, A.K., 2024. AI revolutionizing industries worldwide: A com-

prehensive overview of its diverse applications. Hybrid Advances, p.100277.

Thiel, S. and Bernhardt, J.C., 2023. AI in museums: reflections, perspectives and applications (p. 320). transcript Verlag.

United Nations Educational, Scientific and Cultural Organization (UNESCO) (2019) Report on the implementation of the UNESCO 2015 Recommendation on Museums & Collections. Paris: UNESCO, 7 Place de Fontenoy, 75352 Paris 07 SP, France.

Yun, K., 2024. A Study on the practical value of voice-activated robot guides at museums. Journal of Digital Art Engineering and Multimedia, 11(2), p.205.

Zunino, D., Suarez, F.F. and Grodal, S., 2019. Familiarity, creativity, and the adoption of category labels in technology industries. Organization Science, 30(1), pp.169-190.

Tahar, A., Riyadh, H.A., Sofyani, H. and Purnomo, W.E., 2020. Perceived ease of use, perceived usefulness, perceived security and intention to use e-filing: The role of technology readiness. The Journal of Asian Finance, Economics and Business, 7(9), pp.537-547.

Elgammal, I., Ferretti, M., Risitano, M. and Sorrentino, A., 2020. Does digital technology improve the visitor experience? A comparative study in the museum context. International Journal of Tourism Policy, 10(1), pp.47-67.

Beyond Borders: A Virtual Gateway To Global Universities

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ABSTRACT:

In today's interconnected educational landscape, the ability to explore international institutions plays a crucial role in students' academic planning and mobility. However, in Ghana and many Sub-Saharan African contexts, limited financial resources, geographical distance, and lack of exposure continue to prevent students from engaging with global academic environments. This paper presents Beyond Borders, a concept for a Virtual Reality (VR) Repository at Kwame Nkrumah University of Science and Technology (KNUST), aimed at enabling students and faculty to take immersive, interactive virtual tours of international partner institutions. The purpose of the project is to bridge the gap in global academic access through emerging technologies. The study adopts a conceptual and systems design methodology informed by literature on immersive learning, VR in higher education, and internationalization practices. The design process includes stakeholder analysis, prototype design, and feasibility mapping to assess how a VR-based platform can simulate real campus experiences and foster global engagement. The findings from the conceptual analysis suggest that a VR repository can increase awareness of international study opportunities, support informed academic decision-making, and facilitate cross-border collaboration. It also has institutional benefits, enhancing KNUST's global visibility and supporting Ghana's national digitalization goals and SDG 4 (Quality Education). The proposed platform is expected to benefit students, academic advisors, international offices, and partner universities. This paper contributes to the growing discourse on immersive education in Africa and offers a scalable model for integrating VR into higher education to promote equity, access, and global academic connectivity.

KEYWORDS: Virtual Reality, Immersive Learning, Higher Education, Internationalization, Academic Mobility, Digital Innovation.

1. Introduction

In an increasingly globalized academic environment, the ability to access and explore international learning opportunities has become a vital component of academic planning, student mobility, and institutional partnerships. Yet, for many students and faculty in Ghana and across Sub-Saharan Africa, financial constraints, geographic barriers, and infrastructural limitations restrict the possibility of visiting international institutions in person. As a result, many prospective postgraduate applicants and researchers make decisions with limited insight into the academic, social, and cultural environments of potential study destinations.

The gap in equitable exposure to global learning ecosystems can negatively affect students' decision-making, reduce access to international exchange programs, and limit opportunities for institutional collaboration. In response, digital technologies—particularly immersive tools such as Virtual Reality (VR)—present a transformative opportunity to bridge this divide. Globally, higher education institutions are integrating VR technologies to simulate campus visits, facilitate intercultural exchange, and enhance student engagement beyond geographical boundaries.

This paper introduces Beyond Borders, a proposed VR Repository to be developed at Kwame Nkrumah University of Science and Technology (KNUST). The repository will serve as an immersive and interactive digital platform where users can explore virtual campus tours, cultural content, and academic facilities of international partner institutions across Africa, Europe, Asia, and North America. By simulating physical campus experiences, the platform aims to support informed academic decision-making, promote global exposure, and foster international partnerships.

The project aligns with Ghana's digital innovation agenda and Sustainable Development Goal 4 (Quality Education). It also reinforces KNUST's strategic vision of using emerging technologies to enhance teaching, learning, and global engagement.

2. Literature Review: Immersive Technologies and Internationalization in Higher Education

Virtual Reality (VR) has gained recognition as a powerful educational tool capable of transforming how learners interact with content, environments, and institutions. According to Slater and Wilbur (1997), immersive environments offer a sense of presence that supports deeper engagement, spatial awareness, and contextual

understanding—factors crucial to academic exploration and planning. In higher education, VR applications now span simulations in science, medicine, engineering, architecture, and increasingly, student services such as campus orientation and international recruitment.

Several global universities—including Stanford, MIT, and King’s College London—have developed VR campus tours that allow prospective students to navigate their facilities remotely. These applications provide detailed 360-degree views of classrooms, dormitories, libraries, and laboratories, accompanied by voice-over explanations and cultural insights (Jensen & Konradsen, 2018). Research shows that such immersive content enhances user motivation and decision-making accuracy, especially for students who cannot afford travel (Radianti et al., 2020).

Despite these innovations, many African institutions have yet to fully adopt VR in ways that support internationalization or remote academic exploration. According to UNESCO (2021), access to immersive technologies in African universities is hindered by limited investment, lack of localized content, and insufficient infrastructure. While digitalization efforts are growing, particularly in countries like Ghana, most virtual learning environments remain limited to 2D interfaces and basic interactivity.

Beyond Borders addresses this gap by proposing a repository that leverages VR to bridge exposure inequalities. Unlike existing VR efforts that are institution-specific and often inaccessible from developing contexts, this platform will be collaboratively built and tailored for regional use. Its focus on cross-institutional representation, cultural diversity, and immersive storytelling sets it apart as both a tool for academic exploration and a driver of global academic engagement.

3. Research Methodology

This study adopts a conceptual and systems design methodology, grounded in real-world planning for the implementation of a Virtual Reality (VR) repository. Rather than developing a technical prototype, the focus is on outlining a clear strategy for how the Beyond Borders platform can be established, sustained, and used at KNUST to simulate international academic experiences.

3.1 Research Design

The research follows a design-thinking approach, which begins with identifying barriers to international academic exposure and progresses to designing a VR-based solution aligned with institutional capabilities and user needs. This approach allows for iterative planning based on stakeholder inputs, existing digital infrastructure, and global best practices in immersive learning.

3.2 Data Collection

Data was gathered from the following sources:

- **Desktop research** on global use of VR in higher education
- **Policy reviews** of Ghana's ICT in Education Strategy, KNUST's internationalization agenda, and SDG 4
- **Stakeholder consultations** with university faculty, ICT staff, and international office representatives to determine the types of institutions, programs, and content most relevant to students' academic planning

3.3 VR Content Acquisition Strategy

The key to implementing Beyond Borders is not developing all virtual environments in-house, but curating and organizing high-quality, existing VR tours from global academic institutions. The plan includes:

- **Sourcing existing 360° campus tours** already published online by international universities (e.g., on YouTube, Google VR, Matterport, or official university websites)
- **Requesting partnerships** with international offices of target universities to access unpublished VR content or collaborate in co-producing virtual tours
- **Creating VR content locally** for African partner universities that lack VR documentation, using 360° cameras, narration, and student testimonials recorded on-site

The repository at KNUST will serve as a central studio and access point, hosting all curated or produced content in an organized digital interface.

3.4 Access and Interaction Plan

To ensure accessibility and usability:

- The repository will be hosted on cloud infrastructure with options for offline access in the KNUST E-learning Centre VR labs
- Users can explore the platform via:
 - **VR headsets** (for immersive experience)
 - **Web-based navigation** (for regular desktop/laptop users)
 - **Mobile VR viewers** (e.g., Google Cardboard for budget-conscious access)
- Content will be organized by:
 - Country/region
 - Program type (e.g., Engineering, Humanities, Postgraduate)
 - Institutional collaborations (e.g., exchange-ready, research-active)

3.5 Limitations

This conceptual model does not include usability testing or full-scale content integration. Its success will depend on institutional commitment, partnership development, and access to equipment for local content creation. Future research will be needed to assess impact on student decision-making and international engagement.

4. Findings and Discussion

Although this research does not involve empirical testing or user trials, the conceptual development and contextual analysis of Beyond Borders offer several key insights regarding the feasibility, potential impact, and anticipated challenges of implementing a Virtual Reality (VR) repository for academic exploration at KNUST.

4.1 Feasibility and Institutional Readiness

Preliminary consultations with stakeholders and reviews of institutional capabilities indicate that KNUST possesses the basic infrastructure needed to support a VR content repository. The university's existing VR lab, E-learning Centre, and IT Services Directorate can host and manage immersive content, while future deliberations will focus on providing a viable delivery channel for web and mobile access. Moreover, the university's strategic focus on digital transformation aligns well with the goals of this initiative.

4.2 Global Resource Availability

The abundance of existing VR campus tours and immersive academic content online provides a strong foundation for content curation. Many partner universities across Europe, North America, and even parts of Africa have produced 360° virtual tours that can be legally embedded, repurposed, or linked within the Beyond Borders interface. This reduces the cost and time associated with original content production while still offering authentic experiences.

4.3 Educational and Strategic Impact

The VR repository offers strong potential benefits for students, staff, and institutional decision-makers:

- Students gain realistic exposure to foreign institutions, improving their ability to choose relevant postgraduate programs, research collaborators, and exchange destinations.
- Academic departments can use the platform to introduce students to partner institutions in their fields.
- KNUST's International Programmes Office can leverage the tool to showcase existing partnerships and streamline outbound mobility planning.

The platform also enhances KNUST's visibility as a technology-driven university and strengthens its appeal to international collaborators.

4.4 Accessibility and Equity Considerations

While the system is designed to be broadly accessible, issues of affordability and digital equity remain. Not all students may have access to VR headsets or high-speed internet connections, especially those in rural or low-resource areas. As a result, Beyond Borders is being designed to function across three tiers of accessibility:

1. **High-immersion VR (headset-based)** — available at the KNUST VR Lab.
2. **Mobile and desktop access** — for broader reach across the student population.
3. **Screened demo sessions** — to be organized at faculty and hall levels to ensure inclusivity.

4.5 Key Challenges and Mitigation Strategies

Table 1. Challenges and Proposed responses to implementation of Beyond borders

Challenge	Proposed Response
Content licensing from institutions	Initiate formal content-sharing agreements with selected partners
Device limitations for students	Design for multi-device access and install VR kiosks on campus
Updating and verifying content	Assign dedicated VR content curators or involve student volunteers
Bandwidth and internet access	Use lightweight, compressed 360° content with offline options

4.6 Contribution to Practice and Policy

This paper contributes a practical model for enhancing academic exploration and decision-making using immersive technology. It advocates for the integration of VR into internationalization strategies and offers a replicable approach for African universities looking to increase digital engagement in higher education. The initiative also supports Ghana’s national digital policy and complements ongoing efforts to align tertiary education with global innovation standards.

5. Conclusion and Further Research

This paper has introduced Beyond Borders, a strategic initiative aimed at establishing a Virtual Reality (VR) repository at Kwame Nkrumah University of Science and Technology (KNUST). The project is designed to enhance global academic exploration by enabling students and faculty to virtually tour partner institutions across continents, bridging geographic and financial gaps that have historically limited equitable access to international learning opportunities.

Through a systems-based design approach and contextual analysis, the concept has demonstrated both feasibility and strategic alignment with Ghana's digital education policies and Sustainable Development Goal 4 (Quality Education). The availability of existing VR content, KNUST's growing technological infrastructure, and stakeholder readiness position the university as a strong candidate for implementing and scaling this initiative. Furthermore, the Beyond Borders platform has the potential to support student mobility, foster new academic partnerships, and promote informed postgraduate decision-making.

While the paper does not present empirical findings, it offers a viable implementation roadmap grounded in research, stakeholder input, and institutional capacity. Recognizing the limitations of content access, licensing, and infrastructure disparities, the design emphasizes inclusivity, cross-platform functionality, and collaborative development.

While the current scope focuses on conceptual modelling and implementation planning, future research and development efforts will build on this foundation to explore the following advancements:

- 1. Live VR Campus Tours and Classroom Integration:** Partnering institutions will host live, interactive VR sessions where KNUST students can explore campuses in real time, and even sit in on ongoing lectures, thereby simulating true academic immersion.
- 2. Live VR Conferences and International Events:** The platform will support real-time VR-based academic conferences, workshops, and seminars, enhancing cross-border academic exchange and student exposure.
- 3. VR in Health and Medical Education:** A dedicated VR extension will be developed for KNUST's health faculty, allowing students to simulate surgical procedures, anatomy exploration, and patient interaction in a safe and interactive environment.

These future directions will be supported through phased implementation, research partnerships, and evaluation of user outcomes. As Beyond Borders evolves, it promises to transform KNUST into a regional hub for immersive, equitable, and globally connected education

6. Acknowledgement

The authors wish to acknowledge the contributions of the faculty and administrative staff of the Kwame Nkrumah University of Science and Technology (KNUST), particularly the E-learning Centre, the International Programmes Office, and the University Information Technology Services (UITS) team, whose insights and institutional guidance helped shape the direction of this concept.

We also extend appreciation to the various stakeholders who shared feedback during informal discussions, including academic advisors, international education consultants, and IT support personnel. Their input was instrumental in validating the need for an immersive platform that broadens access to global academic opportunities.

This paper also draws inspiration from ongoing efforts within KNUST to promote digital transformation in higher education, and aligns with the university's broader strategic goals under Ghana's national digitalization agenda.

References

- Chakrabarti, A., Banerjee, S. & Sen, R. (2022), 'Virtual learning environments and internationalization in higher education: A framework for emerging economies', *International Journal of Educational Technology in Higher Education*, 19(1), pp. 1–17.
- Jensen, L. & Konradsen, F. (2018), 'A review of the use of virtual reality head-mounted displays in education and training', *Education and Information Technologies*, 23(4), pp. 1515–1529.
- Radianti, J., Majchrzak, T.A., Fromm, J. & Wohlgenannt, I. (2020), 'A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda', *Computers & Education*, 147, pp. 103778.
- Slater, M. & Wilbur, S. (1997), 'A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments', *Presence: Teleoperators and Virtual Environments*, 6(6), pp. 603–616.
- UNESCO (2021), *Education in a Post-COVID World: Nine Ideas for Public Action*, [online] Available at: <https://unesdoc.unesco.org/ark:/48223/pf0000375706> [Accessed 12 Jun. 2025].

Using Remote Sensing And Drones In Smart Agriculture Training Programs: A Systematic Review

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ABSTRACT:

With the world moving towards Agriculture 4.0, the era of digital revolution in the farming industry, there is a growing need to reform the traditional agricultural education system to one that will equip learners with the skills they will need to meet the smart farming system. This study addresses the gap between the conventional methods of traditional agricultural training and the actual technological competencies required for smart farming environments. The study focuses on the integration of remote sensing and drone technologies in agricultural training and how these technologies will be able to promote capacity in trainees and help to promote responsible innovation and inclusive education in the digital age. Through the systematic review method, the research gathers and analyzes existing literature from reputable databases, such as Google Scholar and Web of Science. The search was narrowed with the help of keywords like “drone technologies”, “remote sensing”, and “agricultural training”. To guarantee the transparency and rigidity of the process of selecting relevant studies, the PRISMA framework was utilized. Initial findings indicate that drones and remote sensing technologies have a positive impact on learning outcomes and digital literacy. However, issues regarding affordability, availability, and the local support system cannot be ignored. The study’s results will inform the development of low-cost, inclusive training programs, providing valuable insight for policymakers, educators, and development stakeholders working with advanced digital tools in agricultural education. In total, 31 studies were systematically reviewed as part of this study.

KEYWORDS: Smart Agriculture, Drone Technology, Remote Sensing, Agricultural Education, Digital Inclusion.

1. INTRODUCTION

Agriculture has come a long way, evolving and transforming over the ages through various stages to respond to the increasing monitoring needs of society. Agriculture was mostly conducted by manual labour, mostly via the skills of the local people, and this was known as Agriculture 1.0. Agriculture 2.0 was the introduction of machinery, the notion was to introduce tractors, irrigation systems, and simple chemical inputs that made agriculture in that season more productive. Next was the Green Revolution and early digital (Agriculture 3.0) that includes better seeds, fertilizers, and simple automation.

Today is the era of Agriculture 4.0 that embraces the intelligent use of digital technologies, including drones, remote sensing, IoT, artificial intelligence (AI), and data analytics to create more intelligent and sustainable agriculture. Remote sensing and drones, also known as Unmanned Aerial Vehicle Systems (UAVS) have transformed the agriculture sector by offering useful insights and improving the decision-making process. The technologies are critical in transforming agriculture, ensuring sustainability, and solving the problems associated with the agriculture industry. Since the global population is growing at a very high rate, it is becoming harder to achieve world food security. To satisfy the food needs of a fast-growing population, agricultural outputs should be increased significantly, and smart farming is an essential and well-timed approach (Islam et al., 2021).

A revolutionary shift in comparison to traditional farming practices is the smart agriculture strategy, as well as technicalities that are considered to generate efficiencies, output, and sustainability in various aspects. (Guevara et al., 2024). The approach implies the integration of technologies, including smart sensors, IoT, big data, and AI, to enable the efficient decision-making process in crop and resource management. (Soussi et al., 2024). Sensing various agricultural parameters, choosing the best sensing locations, collecting data in real time, and routing the data from crop fields to control stations for decision-making and visualizing the results to guide the farmer's decisions (Prakash et al., 2023).

UAVs, high-resolution aerial imagery, and data, and remote sensing can identify crop health, soil conditions, pests, and irrigation demand. Such insights can be valuable to facilitate timely action and optimize the input of water, fertilizers, and

pesticides by the farmers to yield more and also assist in reducing the environmental impacts (Tsouros et al., 2019). In addition, UAVs help improve field inspection operations by reducing the need for manual inspections.

Training programs must be modernized for agriculture professionals in order to facilitate the global acceptance of smart farming techniques, including drones and remote sensing. The training enhances the learner's technical know-how while promoting adaptability and confidence in the use of these tools. Further, incorporating these technologies within education and training programs provides for hands-on learning. Facilitators teach UAVs and remote sensing systems to build confidence in a learning environment that is as hands-on as a real-world encounter the alternative prepares the trainees for careers in high-tech agriculture and aids in providing a skilled workforce to confront the complex needs of the modern food systems (Al-Farabi Kazakh National University et al., 2024; Ayamga et al., 2021).

The growing affordability and accessibility of drone technology also make the case for their inclusion in agricultural education. Radoglou-Grammatikis et al. (2020) state that the ease of access to open-source platforms and off-the-shelf UAV systems makes them a reasonable choice to consider in education, where training can be scaled regardless of the limited resource setting.

Remote sensing and drones in smart agricultural training are not just a technical teaching aid but a strategic choice to empower the new generation of agricultural experts. With the transformation of the agricultural system around the globe, integrating technologies in the training programs will guarantee long-term food security, technological understanding, and the ability to withstand climatic and environmental changes.

Despite the increasing integration of technology in agricultural practices, there remains a significant gap in how training programs incorporate drone and remote sensing technologies, especially in low-resource settings. Therefore, this study aims to systematically review how these technologies are being used in smart agriculture training programs and assess their effectiveness. The objectives of this study are to: (1) evaluate the effectiveness of drone and remote sensing tools in improving training outcomes, (2) identify key challenges and barriers to adoption, and (3) explore opportunities for digital inclusion in agricultural education.

For this purpose, the remainder of this study is organized as follows: Section 2 will present a literature review of similar works done concerning the use of drones and remote sensing technologies in agriculture and training. Section 3 outlines the methodology for conducting the systematic review. Section 4 outlined the results derived from the systematic review. Lastly, section 5 ends the paper, summarising the main findings and suggesting future research and policy implications in the design of inclusive, technology-based agricultural training interventions.

2. LITERATURE REVIEW

In this section, the author explores what other researchers have discovered about the application of drones and remote sensing technologies in an agricultural context. It reveals gaps, advantages, and concerns of interest, providing the foundation of the systematic analysis of the current study.

The authors of (Nezhmetdinova et al., 2021) note that training engineering staff in the agricultural sphere is necessary with the help of innovative technologies, such as smart agriculture, robotization, and the Internet of Things, and introduce agricultural classes that would establish connections between schools and local enterprises to solve the problem of personnel absence and improve career guidance. But in this study, the limitation has been found because it deals with the urban youth and restricts the rural interaction.

Dr. Umesh B. Pawar et al. (2023) discuss that training human resources in the agriculture industry is a last but necessary step in utilizing drone technology. The reasoning behind this is that farmers and field workers need to understand how to operate a drone and analyze the data to make better decisions, have increased productivity and profits within the limits of the local regulations to achieve the best results in agricultural production.

In (de Koff, 2023), the paper includes the article about introducing training on remote pilot certification to agricultural professionals in which the researchers found that there was a high level of knowledge gain and behavior modification after the training session which indicates that drone technology is valuable in transforming agricultural operations and awareness among the farmers.

Chiranjeeb and Beuria (2020) reveal that the use of drone technology, sensors, and GPS in agriculture is at an early stage. Education of staff on these technologies is the key to successful field analysis, crop condition, and health analysis that led to the development of smart farming.

loja et al. (2023) explain the remote sensing and drone application in precision

farming, stating that it helps to maximize efficiency and sustainability in collecting data and vegetation indices to optimize training programs on effective land interaction and crop observation.

Drones can also help to improve smart agriculture training programmed as they allow to analyses the crop health, monitoring of the soil, and management of resources effectively. They enhance the collection of data in real-time to make precision agriculture decisions, eventually promoting crop yield and quality in responding to challenges of food insecurity (Pakeerathan, 2023).

Ram and Arunachalam (2024) surveyed that the use of drones in smart agricultural training programs has become more integrated due to cameras and sensors with high resolutions, solar-powered drone use in aerial surveys to capture images, drone use in evaluating the health of crops, and drone use in managing irrigation efficiently. They enable evidence-based decision-making and ensure environmental sustainability, and minimize the number of agrochemicals in farming activities.

3. RESEARCH METHODOLOGY

This paper employs a systematic review methodology to analyze the implementation of remote sensing and drone technologies in agricultural training, drawing useful conclusions regarding their effectiveness, the challenges faced, and their potential influence on inclusive and contemporary training programs in the future. The current research requires a systematic review, as it allows for the systematic, thorough, and unbiased analysis of existing research on technology adoption and changes in education.

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The study has a qualitative-descriptive design and is based on the principles of systematic review and is built according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. This research design was chosen among many others, including case studies or trials, as it assists in collecting and synthesizing the results for numerous locations, and thereby the conclusions are more valid and generalizable. The concentration on peer-reviewed articles and well-known academic publications offers an influential analysis that informs intelligent agriculture training.

The databases that were used in the systematic literature search were IEEE Xplore, Google Scholar, Web of Science, and Scopus. These sites have been chosen to give

a broad overview of what is currently being researched in this field by encompassing a wide variety of peer-reviewed journal articles, conference proceedings, and technical reports.

The search employed the combination of search keywords, which constituted drone technologies, remote sensing, and agricultural training. Among the significant keywords applied were "drone technology", "agricultural training", "remote sensing", "precision agriculture", "digital agriculture training", "capacity building", "inclusivity learning", "smart farm education", and "UAV".

The priority was given to the studies published between 2019 and 2024 to acquire information on the forecasted and actual trends in drone and remote sensing integration in smart agriculture. Peer-reviewed articles, conference proceedings, and reliable institutional reports that directly covered the topic of drone technologies use, remote sensing use in training or education in an agricultural context were considered, and articles not written in English and those not covering the training material were removed.

A total of 31 studies were included in the final review after applying the inclusion and exclusion criteria. Only English-language publications were considered due to the limitation of translation resources and to ensure consistency in thematic analysis across the reviewed studies.

The most suitable type of review that could be applied in this study was a systematic review because of a few reasons. It admits a high degree of geographic diversity, institutional settings, and technological interventions, and offers both coverage and depth in the comprehension of the research issue. Besides, a systematic review enables drawing on the insights of many different sources that, in combination, provide a much firmer basis to formulate recommendations and policy decisions than single case studies or other limited empirical studies.

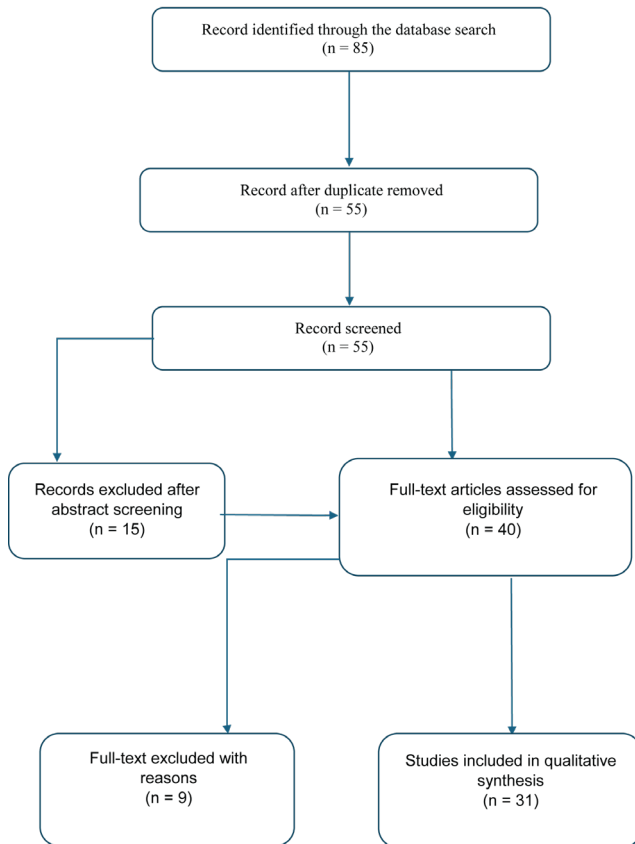


Fig. 1 shows the Prisma framework for this study

In order to increase the transparency and reproducibility of the review process, this research was organized according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. PRISMA is a standardized reporting guideline applied to the reporting of systematic reviews and meta-analyses, which is utilized to ensure that each of the key steps, including records identification and ultimate inclusion, are documented. Four major steps were used in the process, which included database identification of all records (n = 85), elimination

of all duplicates (n = 30), abstract and full-text screening (n = 55), and lastly, the final inclusion of 31 studies based on pre-determined eligibility criteria. This selection process is visualized with the help of a PRISMA flow diagram (Fig. 1). The use of PRISMA allowed minimizing the selection bias and resulted in the synthesis of high-quality, relevant studies only in the review.

4. FINDINGS AND DISCUSSION

This session summarizes insights from the systematic review of literature on integrating drones and remote sensing technologies into agricultural training. The discussion is organized around four emerging themes: (i) training effectiveness, (ii) digital literacy enhancement, (iii) barriers to adoption, and (iv) inclusivity and strategic opportunities.

Table 1: Summary of the reviewed papers with the most relevant ones grouped by key objectives/themes. Each of the 31 reviewed studies is not represented here individually because some provided general or contextual contributions to the findings.

Objective/Theme	No. of Papers	Key Sources
Training Effectiveness	5	de Koff (2023), Iojă et al. (2023), Ram & Arunachalam (2024), Guevara et al. (2024), Radoglou-Grammatikis et al. (2020)
Digital Literacy Enhancement	3	Pawar et al. (2023), Ayamga et al. (2021), Pawar & Deosarkar (2023)
Barriers to Adoption	2	Pakeerathan (2023), Nezhmetdinova et al. (2021)
Inclusivity and Strategic Opportunity	2	Ayamga et al. (2021), Radoglou-Grammatikis et al. (2020)

4. 1 Training Effectiveness

The reviewed literature consistently emphasizes the experiential values of the drone-assisted training. Practical demonstration using UAVs simulates real-life farm scenarios, which leads to better learner retention and comprehension (de Koff, 2023; Iojă et al., 2023). These benefits are reported across developed countries (e.g., the U.S., the EU) and emerging markets, although the level of application differs across contexts.

It is worth noting that (Ram and Arunachalam, 2024) document real-time decision-making improvement as a result of trainees learning to interpret aerial imagery and geospatial data. This aligns with findings from (Guevara et al., 2024) on the broader benefits of IoT and remote sensing in smart farming. In a resource-constrained environment, an open-source UAV platform (Radoglou-Grammatikis et al., 2020) makes training more scalable and adaptable.

Table 2: Comparison of Effectiveness Outcomes by Region

Region	Training Mode	Outcomes Noted	Source(s)
North America	Formal Institutional	Improved decision-making, hands-on skills	(de Koff, 2023)
South Asia	Government-led program	Real-time monitoring, increased adoption	(Ram and Arunachalam, 2024)
Sub-Saharan Africa	NGO & pilot program	Basic digital exposure, limited reach	(Ayamga et al., 2021)

4. 2 Digital Literacy Enhancement

Introducing learners to UAVs and technological tools is noted as one of the main contributors to the improvement of digital literacy levels. The programs give the learners, especially youth, confidence in working with high-tech instruments and orientation in agricultural software (Dr Umesh B. Pawar et al., 2023).

The level of skill development is however not uniform in studies. Training would extend beyond operations to involve data interpretations and integration in a well-funded programme (e.g., EU-funded projects). Conversely, training in a low-income setting usually ends at the point of basic operation because of the lack of resources (Ayamga et al., 2021).

Employability is also substantially enhanced by training, since the graduates would gain pertinent skills to precision agricultural work, which numerous studies, such as Pawar and Deosarkar (2023), who mentioned greater technology acceptability after training.

4. 3 Barriers To Adoption

Nevertheless, the number of challenges restricts the mainstream usage despite the increasing interest.

- i. Cost: Drones and software are expensive, which limits their use in low-budget institutions (Pakeerathan, 2023).
- ii. Infrastructure: Low internet connection and unavailability of technical assistance are deterrents to sustainability
- iii. Policy Gap: Lack of regulation and certification scheme, particularly in the developing world.
- iv. Equity: The rural youth does not have access to such opportunities, in most cases (Nezhmetdinova et al., 2021).

4.4 Inclusivity And Strategic Opportunities

The inclusion implementation is shown by the programs consisting of open-source drones and community-based training models (Ayamga et al., 2021). The certification module of UAV and the digital literacy aspect should be included in national agricultural policies to close the gap between urban and rural areas.

5. Conclusion And Further Research

The involvement of drones and remote sensing technologies in training related to agriculture is a significant breakthrough towards the smart farming concept. These technologies, according to this research, assist trainees in becoming familiar with digital tools and acquiring the experience they require when working in high-tech and data-driven farming surroundings. In the systematic review, it was emphasized that the use of UAVs and remote sensing technologies in training enhances decision-making, operations, and responding to challenges in real time, thus safeguarding sustainable food production as the global demand and environmental issues rise.

The study, however, notes that challenges still exist, such as high cost, inadequate infrastructure, regulatory gaps, and unfair access, especially to the rural and low-income populations. In order to beat these challenges, particular policy interventions, open-source software, and all-embracing training are required to assist individuals who are deprived of technology.

Overall, the implications of the research indicate that the integration of digital technologies into the curriculum of agricultural education is required to achieve the creation of sustainable, resilient, and inclusive food systems. As the agricultural sector expands, educational programs in agriculture must embrace the tools to ensure that learners keep abreast to secure sufficient food for all people in the world.

On the findings and discussions made in the study, future research on how to better integrate remote sensing and drones in agriculture is suggested as follows. The next steps of the research need to be aimed at the organization and realization of the training programs, which will be adjusted to the local demands and will embrace the skills of UAVs and remote sensing. It should be customized according to farming procedures, education levels of skills, and the available technology at the local level, and this should be researched. In addition to that, the research needs to be done on low-cost and scalable training models, based on open-source UAV platforms and mobile learning tools. Their efficacy should be studied in regions with scarce resources, especially in rural and underserved populations.

In the Ghanaian context, the findings make it clear that agricultural training programs need to be narrowed down to focus on rural accessibility, infrastructure development, and capacity building among young people. Through these understandings, Ghanaian policymakers can be in a better position to incorporate UAV certification and remote sensing units into the national agricultural curriculum to

equip the workforce with the readiness to meet the demands of modern farming technologies, and with the available expertise in remote sensing, the impact of these activities can extend to the farming communities.

6. ACKNOWLEDGEMENT

This paper belongs to a larger research project aimed at promoting the use of smart agricultural techniques through the incorporation of emerging technologies in learning and training. The author would also wish to give special thanks to the academic supervisors and colleagues who gave constructive comments towards this work at its initial stages. I also wish to give special thanks to KNUST E-Learning Centre for providing the opportunity and platform that permitted the discovery and implementation of digital learning tools, which formed the base of this research undertaking. This research did not receive any external funding. Nevertheless, the author would like to acknowledge the indirect supervision provided by institutional facilities, as well as the academic guidance that played a substantial role in the successful completion of this paper.

References:

- Al-Farabi Kazakh National University, Sarieva, A.K., Tazhiyeva, S.K., Al-Farabi Kazakh National University, Dossumova, Zh., Kazakh Research Institute of Economy of Agro-Industrial Complex and Rural Development, 2024. Optimizing the quality of training for agriculture: priorities, mechanisms. *Probl. AgriMarket* 241–249. <https://doi.org/10.46666/2024-1.2708-9991.21>
- Ayamga, M., Tekinerdogan, B., Kassahun, A., 2021. Exploring the Challenges Posed by Regulations for the Use of Drones in Agriculture in the African Context. *Land* 10, 164. <https://doi.org/10.3390/land10020164>
- Chiranjeeb, K., Beuria, R., 2020. Role and Application of Drones for Smart Agriculture.
- de Koff, J.P., 2023. Effectiveness of a remote pilot certification training for agricultural professionals. *Nat. Sci. Educ.* 52, e20121. <https://doi.org/10.1002/nse2.20121>
- Dr. Umesh B. Pawar, Shubham K. Darade, Prof. Ramesh P. Daund, Prof. Ravindra Pandit, 2023. An Analysis and Reporting on “Study of Various Drone Technologies available to provide low cost and effective Solutions to Agricultural Sector with Respect to Indian Context.” *Int. J. Adv. Res. Sci. Commun. Technol.* 61–65. <https://doi.org/10.48175/IJARSCT-14209>

- Guevara, I., Ryan, S., Singh, A., Brandon, C., Margaria, T., 2024. Edge IoT Prototyping Using Model-Driven Representations: A Use Case for Smart Agriculture. *Sensors* 24, 495. <https://doi.org/10.3390/s24020495>
- Hadi, T.H., 2024. IoT Protocols: Connecting Devices in Smart Environments. *ICST Trans. Scalable Inf. Syst.* <https://doi.org/10.4108/eetsis.5665>
- Hafeez, A., Husain, M.A., Singh, S.P., Chauhan, Anurag, Khan, Mohd.T., Kumar, N., Chauhan, Abhishek, Soni, S.K., 2023. Implementation of drone technology for farm monitoring & pesticide spraying: A review. *Inf. Process. Agric.* 10, 192–203. <https://doi.org/10.1016/j.inpa.2022.02.002>
- loja, I., Nedeff, V., Agop, M., Nedeff, F.M., 2023. SOME POSSIBILITIES OF THE AERIAL DRONES USE IN PRECISION AGRICULTURE – A REVIEW. *J. Eng. Stud. Res.* 29, 43–49. <https://doi.org/10.29081/jesr.v29i4.006>
- Islam, N., Rashid, M.M., Pasandideh, F., Ray, B., Moore, S., Kadel, R., 2021. A Review of Applications and Communication Technologies for Internet of Things (IoT) and Unmanned Aerial Vehicle (UAV) Based Sustainable Smart Farming. *Sustainability* 13, 1821. <https://doi.org/10.3390/su13041821>
- Istiak, Md.A., Syeed, M.M.M., Hossain, M.S., Uddin, M.F., Hasan, M., Khan, R.H., Azad, N.S., 2023. Adoption of Unmanned Aerial Vehicle (UAV) imagery in agricultural management: A systematic literature review. *Ecol. Inform.* 78, 102305. <https://doi.org/10.1016/j.ecoinf.2023.102305>
- Kim, W.-S., Lee, W.-S., Kim, Y.-J., 2020. A Review of the Applications of the Internet of Things (IoT) for Agricultural Automation. *J. Biosyst. Eng.* 45, 385–400. <https://doi.org/10.1007/s42853-020-00078-3>
- Kumar, S.P., Subeesh, A., Jyoti, B., Mehta, C.R., 2023. Applications of Drones in Smart Agriculture, in: Pakeerathan, K. (Ed.), *Smart Agriculture for Developing Nations: Status, Perspectives and Challenges*. Springer Nature, Singapore, pp. 33–48. https://doi.org/10.1007/978-981-19-8738-0_3
- Nezhmetdinova, F., Valiev, A., Fassakhova, G., Ziganshin, B., Dmitriev, A., 2021. Improving the Quality of Training of Engineering Personnel for the Agro-Industrial Complex. *BIO Web Conf.* 37, 00130. <https://doi.org/10.1051/bio-conf/20213700130>
- Al-Farabi Kazakh National University, Sarieva, A.K., Tazhiyeva, S.K., Al-Farabi Kazakh National University, Dossumova, Zh., Kazakh Research Institute of Economy of Agro-Industrial Complex and Rural Development, 2024. Optimizing the quality of training for agriculture: priorities, mechanisms. *Probl. AgriMarket* 241–249. <https://doi.org/10.46666/2024-1.2708-9991.21>

Ayamga, M., Tekinerdogan, B., Kassahun, A., 2021. Exploring the Challenges Posed by Regulations for the Use of Drones in Agriculture in the African Context. *Land* 10, 164. <https://doi.org/10.3390/land10020164>

Chiranjeeb, K., Beuria, R., 2020. Role and Application of Drones for Smart Agriculture.

de Koff, J.P., 2023. Effectiveness of a remote pilot certification training for agricultural professionals. *Nat. Sci. Educ.* 52, e20121. <https://doi.org/10.1002/nse2.20121>

Dr. Umesh B. Pawar, Shubham K. Darade, Prof. Ramesh P. Daund, Prof. Ravindra Pandit, 2023. An Analysis and Reporting on "Study of Various Drone Technologies available to provide low cost and effective Solutions to Agricultural Sector with Respect to Indian Context." *Int. J. Adv. Res. Sci. Commun. Technol.* 61–65. <https://doi.org/10.48175/IJARST-14209>

Guevara, I., Ryan, S., Singh, A., Brandon, C., Margaria, T., 2024. Edge IoT Prototyping Using Model-Driven Representations: A Use Case for Smart Agriculture. *Sensors* 24, 495. <https://doi.org/10.3390/s24020495>

Hadi, T.H., 2024. IoT Protocols: Connecting Devices in Smart Environments. *ICST Trans. Scalable Inf. Syst.* <https://doi.org/10.4108/eetsis.5665>

Hafeez, A., Husain, M.A., Singh, S.P., Chauhan, Anurag, Khan, Mohd.T., Kumar, N., Chauhan, Abhishek, Soni, S.K., 2023. Implementation of drone technology for farm monitoring & pesticide spraying: A review. *Inf. Process. Agric.* 10, 192–203. <https://doi.org/10.1016/j.inpa.2022.02.002>

loja, I., Nedeff, V., Agop, M., Nedeff, F.M., 2023. SOME POSSIBILITIES OF THE AERIAL DRONES USE IN PRECISION AGRICULTURE – A REVIEW. *J. Eng. Stud. Res.* 29, 43–49. <https://doi.org/10.29081/jesr.v29i4.006>

Islam, N., Rashid, M.M., Pasandideh, F., Ray, B., Moore, S., Kadel, R., 2021. A Review of Applications and Communication Technologies for Internet of Things (IoT) and Unmanned Aerial Vehicle (UAV) Based Sustainable Smart Farming. *Sustainability* 13, 1821. <https://doi.org/10.3390/su13041821>

Istiak, Md.A., Syeed, M.M.M., Hossain, M.S., Uddin, M.F., Hasan, M., Khan, R.H., Azad, N.S., 2023. Adoption of Unmanned Aerial Vehicle (UAV) imagery in agricultural management: A systematic literature review. *Ecol. Inform.* 78, 102305. <https://doi.org/10.1016/j.ecoinf.2023.102305>

Kim, W.-S., Lee, W.-S., Kim, Y.-J., 2020. A Review of the Applications of the Internet of Things (IoT) for Agricultural Automation. *J. Biosyst. Eng.* 45, 385–400. <https://doi.org/10.1016/j.biosysteng.2020.03.001>

doi.org/10.1007/s42853-020-00078-3

Kumar, S.P., Subeesh, A., Jyoti, B., Mehta, C.R., 2023. Applications of Drones in Smart Agriculture, in: Pakeerathan, K. (Ed.), *Smart Agriculture for Developing Nations: Status, Perspectives and Challenges*. Springer Nature, Singapore, pp. 33–48. https://doi.org/10.1007/978-981-19-8738-0_3

Nezhmetdinova, F., Valiev, A., Fassakhova, G., Ziganshin, B., Dmitriev, A., 2021. Improving the Quality of Training of Engineering Personnel for the Agro-Industrial Complex. *BIO Web Conf.* 37, 00130. <https://doi.org/10.1051/bio-conf/20213700130>

Pakeerathan, K. (Ed.), 2023. *Smart Agriculture for Developing Nations: Status, Perspectives and Challenges, Advanced Technologies and Societal Change*. Springer Nature Singapore, Singapore. <https://doi.org/10.1007/978-981-19-8738-0>

Pakeerathan, K., n.d. *Smart Agriculture for Developing Nations*.

Pawar, A., Deosarkar, S.B., 2023. IoT-based smart agriculture: an exhaustive study. *Wirel. Netw.* 29, 2457–2470. <https://doi.org/10.1007/s11276-023-03315-7>

Prakash, C., Singh, L.P., Gupta, A., Lohan, S.K., 2023. Advancements in smart farming: A comprehensive review of IoT, wireless communication, sensors, and hardware for agricultural automation. *Sens. Actuators Phys.* 362, 114605. <https://doi.org/10.1016/j.sna.2023.114605>

Radoglou-Grammatikis, P., Sarigiannidis, P., Lagkas, T., Moscholios, I., 2020. A compilation of UAV applications for precision agriculture. *Comput. Netw.* 172, 107148. <https://doi.org/10.1016/j.comnet.2020.107148>

Ram, A., Arunachalam, A., 2024. DRONE APPLICATIONS IN AGRICULTURE AND AGROFORESTRY. *Int. J. Agric. Sci.* 15, 19–24. <https://doi.org/10.53390/IJAS.2024.15103>

Seelan, S.K., Laguette, S., Casady, G.M., Seielstad, G.A., 2003. Remote sensing applications for precision agriculture: A learning community approach. *Remote Sens. Environ., IKONOS Fine Spatial Resolution Land Observation* 88, 157–169. <https://doi.org/10.1016/j.rse.2003.04.007>

Sishodia, R.P., Ray, R.L., Singh, S.K., 2020. Applications of Remote Sensing in Precision Agriculture: A Review. *Remote Sens.* 12, 3136. <https://doi.org/10.3390/rs12193136>

Soussi, A., Zero, E., Sacile, R., Trincherro, D., Fossa, M., 2024. Smart Sensors and

- Smart Data for Precision Agriculture: A Review. *Sensors* 24, 2647. <https://doi.org/10.3390/s24082647>
- Stehr, N.J., 2015. Drones: The Newest Technology for Precision Agriculture. *Nat. Sci. Educ.* 44, 89–91. <https://doi.org/10.4195/nse2015.04.0772>
- To feed the world in 2050 will require a global revolution [WWW Document], n.d. <https://doi.org/10.1073/pnas.1519841112>
- Tsouros, D.C., Bibi, S., Sarigiannidis, P.G., 2019. A Review on UAV-Based Applications for Precision Agriculture. *Information* 10, 349. <https://doi.org/10.3390/info10110349>
- Ullo, S.L., Sinha, G.R., 2021. Advances in IoT and Smart Sensors for Remote Sensing and Agriculture Applications. *Remote Sens.* 13, 2585. <https://doi.org/10.3390/rs13132585>
- Wang, J., Wang, Y., Li, G., Qi, Z., 2024. Integration of Remote Sensing and Machine Learning for Precision Agriculture: A Comprehensive Perspective on Applications. *Agronomy* 14, 1975. <https://doi.org/10.3390/agronomy14091975>
- Zhang, C., Kovacs, J.M., 2012. The application of small unmanned aerial systems for precision agriculture: a review. *Precis. Agric.* 13, 693–712. <https://doi.org/10.1007/s11119-012-9274-5>

Exploring Problem Orientation And Project Work Outcomes In The BA Integrated Rural Art And Industry Program At KNUST

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ABSTRACT:

This study investigates how problem orientation and formulation within the Problem-Based Learning (PBL) framework influence final-year project outcomes in the BA Integrated Rural Art and Industry (IRAI) Program at Kwame Nkrumah University of Science and Technology (KNUST). Drawing on the Aalborg Model of PBL, the research explores how artistic creativity and technical problem-solving can be better integrated in hybrid, interdisciplinary curricula. Using a qualitative case study design, data were collected from 44 students and 8 lecturers through purposive and proportionate stratified sampling. Data sources included structured surveys, semi-structured interviews, classroom observations, and document analysis. Analytical frameworks included Kirkpatrick's Four-Level Evaluation Model, Mogens Pahuus' typology of problem orientation, and qualitative analysis techniques, combining content and thematic analysis with descriptive statistics. Findings show that when problems are clearly defined and rooted in real-world contexts, students report enhanced engagement, interdisciplinary competence, and creative confidence especially in integrating indigenous art with modern design tools like CAD. Specifically, 85% of students reported increased participation, while 60% observed improved creativity in their project outcomes. However, constraints such as inadequate studio infrastructure, overloaded curricula, and inconsistent PBL implementation across disciplines were noted as barriers to deeper learning. The study does not propose a new model but offers an empirically informed critique of current practices and recommends adapting core principles of the Aalborg PBL model to suit Ghanaian art-and-technology education. It concludes that structured problem formulation guided by Pahuus' typology can provide a clearer pedagogical pathway for balancing artistic exploration with technical rigor. Practical implications include the need for curriculum realignment, faculty development, and expanded access to digital tools to enhance creativity and innovation in indigenous craft and rural industry education.

KEYWORDS: Problem-Based Learning, Aalborg Model, Indigenous Craft, Design Education, Interdisciplinary Curriculum, Project-Based Learning

1. Introduction

The BA Integrated Rural Art and Industry (IRAI) Program at the Department of Indigenous Art and Technology at Kwame Nkrumah University of Science and Technology (KNUST) was established with the purpose of preserving and promoting traditional Ghanaian art forms. According to Druyeh (2008, p.1),

“The programme aims primarily at equipping students with requisite skills to identify and promote the indigenous art and craft of the traditional Ghanaian heritage. It also aims at training students to acquire professional skills in designing, production, and marketing of Ghanaian artistic products that combine practical functions with contemporary aesthetics and the use of local raw materials. Students are also equipped with professional entrepreneurial skills”

The traditional art forms encompassed by the program include ceramics, leatherwork, textiles, woodwork and metalwork, these elements are deeply embedded in Ghanaian cultural heritage and craftsmanship (Druyeh, 2008).

The interdisciplinary nature of the program fosters a hybrid academic model that combines artistic with technical problem-solving (Kek and Huijser, 2011). However, students must preserve the cultural significance of these art forms while acquiring technical skills that transform traditional practices to meet modern industry demands (Agyeman, 2018). Consequently, the IRAI program aims to balance these aspects, preparing students to contribute to both local craftsmanship and global markets (Druyeh, 2008). This aligns with global educational trends, such as the Aalborg University (AAU)'s Art and Technology program, which merges the humanities, fine arts, and engineering sciences to foster artistic and technical innovation (Bertel et al., 2021).

Furthermore, as the IRAI program incorporates a problem-oriented approach, it must also address the complexities of defining an art-and-technology problem in ways that stimulate both creativity and technical proficiency. The IRAI program's community impact highlights its reciprocal knowledge exchange between academia and rural industries.

“In the private sector, the program seeks to create links between the professional education world of the university and the reality of small rural indigenous villages. This programme allows knowledge to transfer both ways, providing the local craft industry with access to new ideas and technology and allowing university students to acquire experiential knowledge of indigenous crafts, enabling them to build on their skills in the marketing of these products”- (Boampong, 2021, p.129).

However, limitations remain, Bukari et al. (2023, p. 17) stated;

“Yet, the few respondents (students: 22.7% and graduates: 11.4%) who said they will not recommend the programme to potential applicants cited lack of well-equipped studios for effective teaching and learning. The finding is supported by Druyeh (2008) after studying the Integrated Rural Art and Industry Programme in KNUST and its impact on the Art/Craft Industry in Ghana. The study revealed that all the IRAI graduates in Ghana’s education sector felt there is the need for the conditions in the department of IRAI, for example, tools and equipment, teaching strategies, relevant teaching and learning materials improved to fully equip graduates to meet the challenges of this growing and technological world.”

Despite its interdisciplinary focus, the program faces several challenges in effectively integrating artistic methodologies with technical problem-solving. Currently, problem orientation within the IRAI curriculum emphasizes artistic creativity but lacks a structured approach to technical rigor, leaving students struggling to balance these two essential components. As a result, students' final-year projects, which are intended to demonstrate their cumulative learning, often excel in creativity but lack the technical depth required for contemporary industry standards (Amedorme & Fiagbe, 2013).

Programs such as the Art and Technology Program at Aalborg University (AAU) have successfully addressed these challenges by utilizing the Aalborg Model of Problem-Based Learning (PBL). This model supports students in defining and solving real-world problems that integrate both artistic exploration and technical expertise (Miliou & Angeli, 2023; Efstratia, 2014; Larmer & Mergendoller, 2010). In contrast, the IRAI program’s current approach to problem orientation does not provide a systematic framework for students to formulate art-and-technology problems. This absence of structured problem formulation limits students' ability to develop projects that are both creatively innovative and technically sound, thereby hindering their ability to integrate into modern industries where art and technology must coexist harmoniously.

Without clear guidance in problem orientation, students often struggle to connect traditional art forms with modern industrial applications, resulting in projects that may reflect creative excellence but fail to meet the technical demands of the industry (Drueyeh, 2008; Bukari et al., 2023). By introducing a structured problem formulation approach that incorporates both artistic and technical problem-solving, the IRAI program can better prepare students for the complex, interdisciplinary

challenges they will face in their professional careers (Jespersen, 2018). This study seeks to explore how the Aalborg Model of Problem-Based Learning (PBL) can be adapted to the BA Integrated Rural Art and Industry (IRAI) program at KNUST to enhance problem orientation, improve project outcomes, and foster greater creativity and technical innovation in students' work. Specifically, it aims to relate the cross-disciplinary structure of the IRAI program akin to the Art and Technology model at Aalborg University to the pedagogical principles of PBL. The overarching research question guiding this inquiry is:

What constitutes a problem in Art and Technology, and how does problem formulation influence both artistic and academic outcomes in the IRAI program at KNUST? Accordingly, the study investigates how the processes of problem orientation and problem formulation, when applied within a PBL framework, can support both creative exploration and academic rigor in students' final-year projects.

2. Review of Related Literature

Problem-Based Learning (PBL) has gained widespread recognition for its ability to foster student-centered learning and real-world problem-solving across disciplines. This review explores how PBL is applied within art and technology education, with a focus on the BA Integrated Rural Art and Industry (IRAI) program at KNUST, and draws comparisons with the Aalborg Model, a benchmark for interdisciplinary PBL implementation.

PBL is rooted in constructivist theory, where learners actively construct knowledge by solving real-world problems (Servant-Miklos, 2020). Ferreira and Trudel (2012) argue that PBL enables learners to merge theoretical knowledge with practical skills, particularly in creative disciplines. Similarly, Hmelo-Silver (2004) emphasizes that the ill-structured nature of PBL tasks deepens learning through contextual and collaborative inquiry.

Originally developed in medical education, Barrows (1986) introduced PBL to counteract rote learning, encouraging students to integrate knowledge through authentic cases. Since then, PBL has been adapted in engineering, social sciences, and the arts (Jespersen, 2018). Savery (2009) highlights the facilitator's role in fostering autonomy, a critical feature in interdisciplinary programs such as IRAI.

Servant-Miklos (2020) distinguishes between PBL and problem-oriented project work: the former often involves instructor-led inquiry, while the latter emphasizes student-defined problem-solving. Perrenet et al. (2000) suggest this flexibility supports learners at different stages, and Michel (2009) proposes blending the two

approaches as seen in the Aalborg Model to enhance interdisciplinary education.

Foundational theories by Bamberger and Schön (1983) and Kolb et al., (2014) on experiential learning and reflective practice—influence the Aalborg Model (Pardjono, 2016). According to De Graaff and Kolmos (2007), the model is guided by five principles: problem orientation, project organization, exemplarity, collaboration, and student responsibility. Jespersen (2018) and Kolmos et al. (2020) affirm that these principles enable students to tackle complex interdisciplinary problems and develop transferable knowledge across technical and creative domains.

Additionally, Jespersen (2018) incorporates Pahuus's typology of problem orientation, which categorizes problems as humane-societal, practical-productive, or theoretical. This framework is especially relevant to hybrid curricula like IRAI. Ulger (2018) found that practical-productive problems enhance creativity, though structured reflection is necessary to support critical thinking. Defining meaningful problems becomes increasingly complex when navigating multiple disciplinary expectations.

The BA in Art and Technology at Aalborg University exemplifies this model. Projects grounded in interdisciplinary themes result in both creative outputs and academic reports. These are shaped by Kolb's experiential learning and Schön's reflective cycle, promoting iteration and deep engagement. According to Servant-Miklos (2020) and Michel (2009), PBL and project work share a real-world orientation but differ in how problems are framed either by facilitators (PBL) or students (project work).

In IRAI, students navigate the convergence of indigenous art and modern industry (Agyeman, 2018). As Andersen and Heilesen (2015) explain, project-based work fosters intellectual ownership when instructors act as co-investigators. A hybrid of PBL and project work as advocated by Kek and Huijser (2011) and Du et al. (2009) may best support interdisciplinarity and innovation in this context.

The Aalborg Model, with its focus on collaborative, project-based, and real-world learning, provides a valuable template for implementing PBL in art and technology education (Allen et al., 2011). The model is theoretically grounded in constructivism and experiential learning and is adaptable across contexts that demand both creativity and technical proficiency (Amaral, 2021).

Figure 2.1 illustrates Pahuus's three types of problem orientation, reinforcing how different knowledge production types; humane-societal, practical-productive, and theoretical can help shape student inquiry in interdisciplinary programs like IRAI

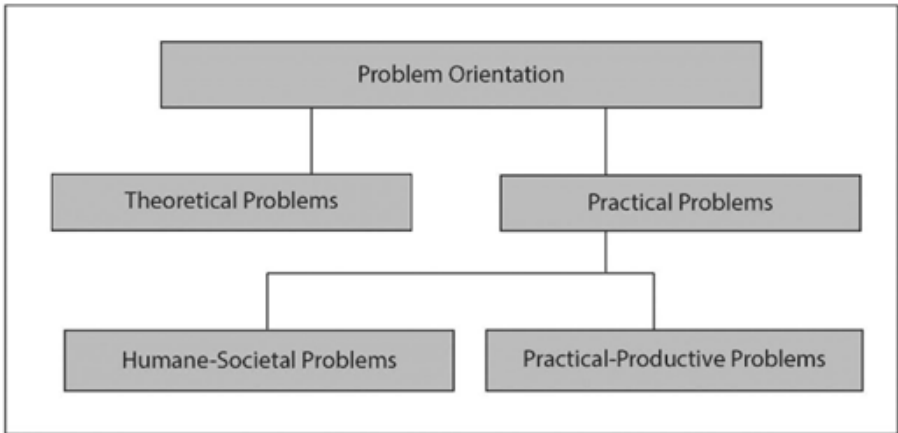


Figure 1.1 Diagram from Mogens Pahuus' three types of problem orientation
(Source: Jespersen, 2018)

Ulger (2018) further emphasizes that creativity flourishes when students address open-ended, real-world problems. However, the lack of structured reflection may hinder critical analysis (Bielefeldt, 2013). This suggests a need for curricula like IRAI's to balance imaginative freedom with analytical depth.

In the IRAI context, students engage with Ghanaian cultural practices and modern industrial tools, blending tradition and innovation. As Baines et al. (2021) and Lucas & Goodman (2015) argue, grounding education in authentic cultural contexts enhances creativity and applied skills, making PBL especially effective.

The Aalborg University BA in Art and Technology curriculum offers a model of how interdisciplinary learning can be structured. Each semester builds on increasingly complex themes, with projects combining technical and artistic problem-solving (Jespersen, 2018). Students are challenged to develop dual competencies, preparing them to address real-world design and production challenges. Through iterative, reflective project work, they learn to balance creative expression with technical rigor—an approach consistent with Kolb and Schön's theories.

This empirical analysis provides insight into how different educational models influence problem formulation, student engagement, and learning outcomes in art and technology fields. Reviewing the variations among these models, particularly Aalborg's, informs how KNUST can optimize its curriculum for improved prob-

lem-oriented outcomes. This comparative review illustrates how different models particularly Aalborg’s can guide curriculum enhancement in IRAI. It informs KNUST’s ongoing efforts to improve student engagement, problem formulation, and interdisciplinary learning outcomes through PBL.

Table 2.1 Compares this approach with KNUST’s IRAI program, highlighting the former’s success in bridging creative and technical competencies through structured, interdisciplinary project cycles. Although PBL and problem-oriented project work share core principles of student-centred inquiry and collaboration, they differ in execution and pedagogical intent.

Table 2.1 Comparative Educational Principles and Intellectual Influences

Aspect	Foundational Principles	Educational Approach	Interdisciplinary Focus	Challenges	Application in Art and Technology
Aalborg University	Constructivism influenced by Dewey’s pragmatism and Rogerian humanism	Project-based learning cycles throughout the semester	Strong emphasis on comprehensive interdisciplinary problem exploration	Less noted; strong emphasis on real-world applicability	Integrated approach with a focus on real-world relevance
Roskilde University	Constructivism influenced by critical theory and Frankfurt School	Emphasis on social contexts and critical reflection	Strong emphasis on social aspects and critical thinking	Focus on critical engagement may limit practical applications	Socially engaged art practices
Maastricht University	Constructivism influenced by Piaget’s constructivist psychology	Structured, smaller problem cycles focusing on cognitive development	Shorter problem cycles with limited interdisciplinary focus	Shorter problem cycles may limit depth of exploration	Structured and cognitive-focused but less applied
KNUST’s BA Integrated Rural Art and Industry	Constructivism influenced by Dewey’s pragmatism with emphasis on integrated rural art and technology	Dynamic learning environment with project work addressing local cultural contexts	Attempts to blend indigenous materials, concepts, ideas and techniques, though faces challenges in full PBL integration	Overly artistic oriented neglecting technical rigor and collaborative design thinking	Integrated approach with Dynamic projects that integrate indigenous art and technology

3 Materials and Methods

3.1 Data Collection

Data collection took place from March to July 2024 and involved the administration of questionnaires, semi-structured interviews, classroom observations, and document analysis. The respondents included students and lecturers from the Department of Indigenous Art and Technology at KNUST, selected based on their direct exposure to Problem-Based Learning (PBL) in the Integrated Rural Art and Industry (IRAI) programme.

Questionnaires were distributed via Google Forms and printed copies, depending on participant accessibility. Approximately 70% of the items were closed-ended Likert scale questions, while 30% were open-ended prompts designed to elicit deeper reflections on PBL experiences. In total, 44 students and 8 lecturers participated in the study. Students were selected through purposive and proportionate stratified sampling, while lecturers were chosen based on their active engagement in PBL instruction.

The questionnaire items focused on four major constructs; engagement, conceptual understanding, skill development, and curriculum flexibility. Interviews were guided by the same constructs and conducted in person or via telephone, depending on availability. Observations were conducted during PBL sessions in studios and classrooms, with emphasis on team dynamics, inquiry patterns, and project formulation. Secondary data included departmental curriculum reviews, sample student project.

Table 3.1 Main Sections of the Questionnaire and Overview of Questions

Sections	Overview of Questions
Engagement	i. Participation in PBL activities ii. Motivation to collaborate in group work iii. Interest in subject matter due to PBL
Understanding & Application	i. Clarity of concepts through PBL ii. Understanding of art-and-technology integration iii. Application of PBL knowledge to real-world contexts

Skill Development	i. Teamwork and collaboration ii. Problem-solving ability iii. Technical skill confidence
Curriculum Flexibility	i. Flexibility to personalize projects ii. Time constraints limiting exploration iii. Instructor support in adapting project themes

3.2 Data Analysis

Data were analyzed using both content and thematic approaches. Initial coding of open-ended responses, interview transcripts, and observation notes was carried out in Microsoft Excel. Responses were sorted by frequency and relevance to the four major constructs. Subsequently, thematic analysis following Braun and Clarke's (2006) six-step framework was conducted to identify key themes aligned with the study's objectives.

Emerging themes were grouped under engagement, conceptual understanding, skill development, and implementation challenges. Inter-coder reliability was assessed through dual coding of transcripts, resulting in a Cohen's Kappa coefficient of $\kappa = 0.83$, indicating substantial agreement. Discrepancies were resolved through discussion between coders.

3.3 Ethical Considerations

Ethical clearance was obtained from the Head of Department, Indigenous Art and Technology, KNUST. Participation was voluntary, with all respondents providing informed consent. Confidentiality was assured throughout the research process in line with institutional ethical standards.

4. Findings and Discussion

This study used Pahuus's typology of problem orientation, Kirkpatrick's four-level evaluation model, and Creswell's qualitative analysis techniques to explore how PBL practices within the IRAI program influenced student outcomes. The findings were categorized under engagement, skills development, implementation challenges, and interdisciplinary effectiveness.

4.1 Results

4.1.1 Student Engagement and Learning Outcomes in the IRAI Program

The first objective of this study was to evaluate how the Aalborg Model supports student learning within the IRAI program. According to Kirkpatrick's first level (reaction), data from the 44 student respondents showed that a strong majority expressed positive reactions to Problem-Based Learning (PBL). Specifically, 24 students (55%) strongly agreed that the PBL approach made them more interested in the subject matter, while 22 students (50%) strongly agreed that they felt motivated to participate in group discussions. Additionally, 20 students (45%) strongly agreed that they felt actively engaged during PBL activities.

These findings suggest that PBL positively influenced students' cognitive and emotional investment in their learning. Students participated in semester and final-year projects across six specializations, with product design (CAD) serving as a common platform for solving real-world problems. Qualitative data from interviews and open-ended responses revealed that students valued working with practical-productive problems involving indigenous materials and community relevance—aligned with Pahuus's typology of context-sensitive problem orientation.

The results presented in Table 4.1 affirm Kolb's theory of experiential learning, indicating that students not only engaged deeply with content but also developed greater confidence in applying skills collaboratively and independently. These findings form the foundation for the proposed IRAI-PBL Adaptive Framework.

Table 4.1 Student Engagement Levels in PBL (n = 44)

Engagement Item	Strongly Agree (n)	Agree (n)	Neutral (n)	Disagree (n)	Strongly Disagree (n)
I felt actively engaged during PBL activities.	20	18	4	2	0
I was motivated to participate in group discussions.	22	15	4	3	0
The PBL approach made me more interested in the subject matter.	24	13	4	3	0

(Source: Field data, 2024)

4.1.2 Student Understanding of Concepts

This section presents student responses on how Problem-Based Learning (PBL) enhanced their understanding of theoretical and applied concepts within the IRAI programme. The findings are drawn from Likert scale survey items, presented in Table 4.2

Table 4.2: Student Responses on Understanding of Concepts through PBL (n = 44)

Survey Item	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
PBL enhanced my understanding of core concepts.	29 (65.9%)	9 (20.5%)	4 (9.1%)	2 (4.5%)	0 (0.0%)
Real-world application made abstract ideas clearer.	29 (65.9%)	8 (18.2%)	4 (9.1%)	3 (6.8%)	0 (0.0%)

I understand the integration of art and technology better through PBL.	28 (63.6%)	10 (22.7%)	3 (6.8%)	3 (6.8%)	0 (0.0%)

(Source: Field data, 2024)

The results from Table 4.2 reveal a strong consensus among students regarding the effectiveness of Problem-Based Learning (PBL) in enhancing conceptual understanding within the IRAI programme. Across all three items surveyed, more than 85% of respondents either agreed or strongly agreed that PBL improved their grasp of course content. Specifically, 29 students (65.9%) strongly agreed and 9 (20.5%) agreed that PBL enhanced their understanding of core concepts, while 29 students (65.9%) strongly agreed and 8 (18.2%) agreed that real-world application made abstract ideas clearer.

Similarly, 28 students (63.6%) strongly agreed and 10 (22.7%) agreed that PBL improved their understanding of the integration of art and technology demonstrating overall agreement rates between 84% and 86% across all items. Only six students expressed neutral or disagreeing views, and no participant selected "Strongly Disagree" for any item, suggesting a consistently positive perception of PBL. These findings affirm that PBL not only fosters student engagement but also promotes deeper, applied learning by bridging theory and practice.

The prevalence of "Strongly Agree" responses underscores the effectiveness of PBL in helping students conceptualize complex relationships, such as the integration of traditional Ghanaian artistic practices with modern technologies like CAD. The near-total absence of negative responses further indicates that students find the PBL approach cognitively enriching particularly in navigating interdisciplinary, real-world problems that require both creative and technical reasoning. These results reinforce theoretical frameworks including Kolb's experiential learning and Pahuus's epistemic problem orientation, both of which highlight the importance of learning through application, contextual inquiry, and reflective practice.

4.1.3 Skill Improvement

Skill development is one of the most valued outcomes of engaging with Problem-Based Learning (PBL), particularly under the Aalborg Model, which emphasizes real-world application, collaboration, and student autonomy. Within the IRAI programme, students reported significant gains in collaborative competence, critical problem-solving, and technical proficiency.

Survey data showed a strong consensus on the positive impact of PBL on skills development, with at least 85% of students agreeing or strongly agreeing that they improved in key areas. In particular, technical confidence recorded the highest "Strongly Agree" response, with 60% (26 students) indicating substantial improvement. Similarly, collaboration skills and problem-solving abilities received high approval ratings, with minimal disagreement or neutrality across all items. Notably, no student selected "Strongly Disagree" for any of the skill improvement items, an indication of strong overall approval.

Table 4.3: Student Responses on Skill Improvement through PBL (n = 44)

Survey Item	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
PBL improved my collaboration skills.	22 (50.0%)	14 (31.8%)	5 (11.4%)	3 (6.8%)	0 (0.0%)
I developed better problem-solving skills through PBL.	24 (54.5%)	13 (29.5%)	4 (9.1%)	3 (6.8%)	0 (0.0%)
I feel more confident in my technical skills after completing PBL projects.	26 (59.1%)	12 (27.3%)	4 (9.1%)	2 (4.5%)	0 (0.0%)

(Source: Field data, 2024)

4.2 Challenges in Implementing the Aalborg Model

Despite the many benefits associated with Problem-Based Learning (PBL) in the IRAI programme, several key challenges were identified, particularly at the behaviour and results levels of Kirkpatrick’s evaluation model. These challenges affected both the implementation and the impact of PBL on deeper student learning outcomes.

Survey responses showed that 29 out of 44 students (66%) reported resource limitations including inadequate access to tools, machines, and raw materials as major obstacles that restricted their ability to fully explore project ideas. Similarly, 31 students (70%) indicated that they were overwhelmed by the demands of practical coursework, which left insufficient time for theoretical reflection or revision. These time pressures were particularly pronounced among final-year students, who were required to complete complex, interdisciplinary projects under tight timelines.

Another concern raised was inconsistency in PBL implementation across disciplines. Some students noted that while departments such as Metal Fabrication and Product Design embraced hands-on, exploratory learning, others remained reliant on theoretical instruction, reducing the uniformity of the PBL experience. This inconsistency was echoed by faculty, who cited curriculum overload and the lack of structured interdisciplinary collaboration as limiting factors.

Faculty interviews also highlighted capacity-related challenges. While most lecturers were supportive of PBL in principle, some acknowledged difficulties in facilitating hybrid pedagogy especially in guiding students through projects that demanded both aesthetic sensitivity and technical proficiency. Several faculty members suggested that without targeted training in interdisciplinary supervision and reflective facilitation, PBL may not achieve its full potential. The combined student and faculty perspectives are summarized in Table 4.4, which compares their perceptions of PBL’s strengths and limitations.

Table 4.4: Summary of Student and Faculty Perceptions of the Aalborg Model's Effectiveness (n = 44 students, n = 8 faculty)

Perception	Student Frequency (n)	Student (%)	Faculty Frequency (n)	Faculty (%)
Enhanced creativity and innovation	37	84.1%	7	87.5%
Improved critical thinking and problem-solving	35	79.5%	7	87.5%
Effective in knowledge integration	34	77.3%	6	75.0%
Resource and time management challenges	29	65.9%	6	75.0%

(Source: Field data, 2024)

While both students and faculty reported high appreciation for the creative and problem-solving potential of the Aalborg Model, differences emerged in how challenges were framed and prioritized. For example, although 65.9% of students cited resource and time management issues, faculty placed slightly more emphasis on these limitations (75%), often linking them to structural constraints such as workshop capacity, limited studio hours, and lack of collaborative planning time between departments.

4.3 Discussion

4.3.1 Availability and Infrastructure Challenges

The study has shown that although students at KNUST's IRAI program are highly engaged in PBL, their learning experiences are limited by resource availability. Similar to observations made in other PBL-based institutions by Kolmos et al. (2020), 67% of students in this study noted that access to advanced tools, materials, and dedicated workshop spaces was insufficient. This situation mirrors Jespersen's (2018) argument that effective PBL requires material conditions that support active experimentation and iterative design. Time constraints were another major challenge. Content analysis done by the researchers on the IRAI curriculum revealed that the curriculum is heavily loaded with both studio-based and theoretical content, students found it difficult to strike a balance between practical work and reflective thinking. This is consistent with Kolb's experiential learning cycle, which requires a balance of doing and reflecting (Pardjono, 2016). Without adequate time for reflection, the deeper conceptual gains expected from PBL are undermined.

4.3.2 Pedagogical Gaps and Inconsistencies

While the IRAI program aims to integrate indigenous materials, concepts, ideas, techniques and art forms with modern technology, inconsistencies in teaching methods were evident. For instance, the use of CAD tools was well developed in Metal Fabrication courses but underutilized in Fibres and Fabrics disciplines. These inconsistencies suggest that faculty development in interdisciplinary and hybrid pedagogy is urgently needed. As noted by Allen et al. (2011), the success of PBL depends heavily on instructors' ability to facilitate open-ended, student-centred learning environments. The Aalborg Model's emphasis on students' autonomy and interdisciplinary collaboration was only partially realized in practice. Although students were encouraged to formulate their own problems, some lacked guidance in connecting artistic goals with technical execution. This echoes Amaral (2021), who warns that poorly defined problems can weaken PBL's impact on creativity and learning. Faculty interviews suggested that students often needed scaffolding

to frame challenges effectively, indicating a need for training in problem formulation methodologies as part of the IRAI curriculum.

4.3.3 Creativity, Innovation, and Interdisciplinary Learning

Despite these setbacks, the IRAI program demonstrated strong outcomes in fostering creativity and interdisciplinary thinking. Projects like Rattan and Bamboo Home Décor and Spectacle Frames from Coconut Shells exemplified how students successfully blended Ghanaian heritage with modern industrial approaches. These outcomes resonate with Schön's reflective practice model, where real-world engagement enables learners to integrate tradition and innovation through iterative design. Problem formulation played a key role in shaping project outcomes. Students who received clearer support in defining problems reported higher confidence in their creative and technical outputs (Kolmos et al., 2020). This supports findings by Jespersen (2018) that exemplary problems serve as anchors for transferable skills and sustained innovation.

4.4.4 Problem Typologies in the IRAI Program

Students in the IRAI program tackle practical-productive problems that merge creative expression with technical application (Jespersen, 2018). Clear problem formulation enhances innovation and engagement, while vague problems hinder outcomes. The Aalborg Model supports structured collaboration and interdisciplinary learning (Amaral, 2021; Bielefeldt, 2013). PBL also builds critical thinking and psychological literacy that supports observations made by Kek and Huijser (2011), making it a strong model for IRAI's hybrid pedagogy. The IRAI program's implementation of PBL not only has the potential to support Active learning but also transitions basic educational inquiry into applied innovation, establishing a foundation for advanced development and facilitating pathways for technology transfer to indigenous and rural industry sectors.

5. Conclusion and Further Research

This study has shown that the implementation of Problem-Based Learning (PBL) within the BA Integrated Rural Art and Industry (IRAI) programme at KNUST has contributed meaningfully to student engagement, creativity, and interdisciplinary learning. Framed through the Kirkpatrick Evaluation Model, the findings reflect positive responses at multiple levels. At the reaction level (Level 1), a significant majority of students reported that PBL activities increased their interest in course content and made learning more engaging. At the learning level (Level 2), students noted improvement in technical skills, teamwork, and the ability to relate aca-

demic knowledge to real-world challenges. This suggests that PBL helped them develop essential competencies such as collaboration, innovation, and applied problem-solving. At the behaviour level (Level 3), evidence from classroom observations and student project outputs showed that learners were actively applying creative thinking and technical knowledge to complex, culturally rooted design problems. Though long-term results (Level 4) such as professional performance were not within the scope of this study, the practical orientation of projects points to likely positive outcomes in industry and entrepreneurial settings. Moreover, the types of problems explored by students in the programme aligned closely with Pahuus' typology of problem orientation. Most of the projects addressed practical-productive problems, focusing on the design and creation of artifacts that integrated indigenous aesthetics with modern manufacturing techniques. There were also elements of humane-societal problems, especially where students engaged with social, cultural, and environmental themes relevant to Ghanaian contexts. Theoretical problems, while less prominent, surfaced in reflective essays and conceptual discussions guided by facilitators. The diversity of problem types suggests that the IRAI programme has begun to cultivate a balanced orientation, equipping students with both creative fluency and practical capability. However, the study also revealed challenges that hinder optimal PBL implementation. Resource limitations, particularly in studio tools, machines, equipment, and materials combined with overloaded curricula, restricted students' ability to explore project topics deeply or iterate effectively. Inconsistencies in interdisciplinary coordination and limited time for guided reflection, a core component of experiential learning, further reduced the overall learning impact, particularly at the behavioural and results levels of the Kirkpatrick model. While the IRAI programme demonstrates strong potential in using PBL to support hybrid education, these challenges underscore the need for improved infrastructure, more deliberate faculty capacity building, and clearer strategies for integrating PBL across art and technology domains. Although this study does not present or validate a formal model, its findings offer grounded insights that lay the foundation for a localized adaptation of the Aalborg PBL framework, one tailored to the cultural, material, and pedagogical contexts of Ghanaian art-and-technology education. By highlighting the importance of structured problem formulation and interdisciplinary balance, the study contributes practical and conceptual guidance for developing context-sensitive PBL approaches in resource-constrained environments. Future research could explore scalable hybrid PBL models suited for such contexts, with attention to how problem orientation, guided by Pahuus's categories, can enhance creativity, critical thinking, and innovation in Ghanaian higher education

6. Acknowledgement

This paper is based on a PGDE project work submitted to the University of Education, Winneba. The author acknowledges the guidance and supervision of Ms. Naomi Acheampong and the support of faculty and students from Kwame Nkrumah University of Science and Technology's Department of Indigenous Art and Technology.

Agyeman Kwaku Duah, G., 2018. Evaluation of the Teaching and Learning of 3-D Computer-Aided Design in the Department of Integrated Rural Art and Industry, Knust (Doctoral dissertation, KNUST).

Allen, D.E., Donham, R.S. and Bernhardt, S.A., 2011. Problem-based learning. New directions for teaching and learning, 2011(128), pp.21-29.

Amaral, J.A.A.D., 2021. Using project-based learning to teach project-based learning: lessons learned. *Pro-Posições*, 32, p.e20180135EN.

Amedorme, S.K. and Fiagbe, Y.A., 2013. Challenges facing technical and vocational education in Ghana. *Cell*, 233, p.244833980.

Andersen, A.S. and Heilesen, S.B. eds., 2015. The Roskilde model: Problem-oriented learning and project work (pp. 121-139). Cham: Springer.

Baines, A. and DeBarger, A., 2021. Key Principles for Project-Based Learning. Rigorous Project-Based Learning: An Inquiry-Based Educational Approach. Lucas Education Research, George Lucas Educational Foundation.

Bamberger, J. and Schön, D.A., 1983. Learning as reflective conversation with materials: Notes from work in progress. *Art Education*, 36(2), pp.68-73.

Barrows, H.S., 1986. A taxonomy of problem-based learning methods. *Medical education*, 20(6), pp.481-486.

Bertel, L.B., Askehave, I., Brohus, H., Geil, O., Kolmos, A., Ovesen, N. and Stoustrup, J., 2021. Digital Transformation at Aalborg University: Interdisciplinary Problem- and Project-Based Learning in a Post-Digital Age. *Advances in Engineering Education*.

Bielefeldt, A.R., 2013. Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students. *Sustainability*, 5(10), pp.4479-4501.

Boampong, M., 2021. Overview of youth development in Ghana. [online] Retrieved from https://www.researchgate.net/publication/360796865_Overview_of_Youth_Development_in_Ghana

- Braun, V. and Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2), pp.77-101.
- Bukari, M., Osei-Poku, P. and Kofi Howard, E., 2023. Evaluating the higher national diploma industrial art programme of tamale technical university in Ghana: Curriculum versus implementation. *Cogent Education*, 10(1), p.2199107.
- De Graaff, E., & Kolmos, A., 2007. *Management of change: implementation of problem-based and project-based learning in engineering*. Brill.
- Druyeh, E.A., 2008. *The Integrated Rural Art and Industry Programme in KNUST and its Impact on the Art/Craft Industry in Ghana (Doctoral dissertation)*.
- Du, X., De Graaff, E. and Kolmos, A., 2009. PBL–Diversity in research questions and methodologies. In *Research on PBL practice in engineering education* (pp. 1-7). Brill.
- Efstratia, D., 2014. Experiential education through project based learning. *Procedia-social and behavioral sciences*, 152, pp.1256-1260.
- Ferreira, M.M. and Trudel, A.R., 2012. The impact of problem-based learning (PBL) on student attitudes toward science, problem-solving skills, and sense of community in the classroom. *Journal of classroom interaction*, pp.23-30.
- Hmelo-Silver, C.E., 2004. Problem-based learning: What and how do students learn?. *Educational psychology review*, 16, pp.235-266.
- Jespersen, L.M.B., 2018. Problem orientation in art and technology. *Journal of Problem Based Learning in Higher Education*, 6(1), pp.1-14.
- Kek, M.Y.C.A. and Huijser, H., 2011. The power of problem-based learning in developing critical thinking skills: preparing students for tomorrow's digital futures in today's classrooms. *Higher Education Research & Development*, 30(3), pp.329-341.
- Kolb, D. A., Boyatzis, R. E., & Mainemelis, C., 2014. Experiential learning theory: Previous research and new directions. In *Perspectives on thinking, learning, and cognitive styles* (pp. 227-247). Routledge
- Kolmos, A., Bertel, L. B., Holgaard, J. E., & Routhe, H. W., 2020. Project types and complex problem-solving competencies: Towards a conceptual framework. In *8th International Research Symposium on PBL* (pp. 56-65). Aalborg Universitetsforlag.
- Larmer, J. and Mergendoller, J.R., 2010. Seven essentials for project-based learning. *Educational leadership*, 68(1), pp.34-37.
- Lucas, N. and Goodman, F.R., 2015. Well-being, leadership, and positive organi-

zationalscholarship: A case study of project-based learning in higher education. *Journal of Leadership Education*, 14(4), pp.138-152.

Michel, J., 2009. Management of change-implementation of problem-based and project-based learning in engineering.

Miliou, O. and Angeli, C., 2023. The Impact of a Project-Based Learning Environment on the Development of Undergraduate Students' Digital Literacy Skills. *International Association for Development of the Information Society*.

Pardjono, P., 2016. Active learning: The Dewey, Piaget, Vygotsky, and constructivist theory perspectives. *Jurnal Ilmu Pendidikan Universitas Negeri Malang*, 9(3), p.105376.

Perrenet, J.C., Bouhuijs, P.A. and Smits, J.G., 2000. The suitability of problem-based learning for engineering education: theory and practice. *Teaching in higher education*, 5(3), pp.345-358.

Savery, J.R., 2009. Problem-based approach to instruction. In *Instructional-Design Theories and Models*, Volume III (pp. 155-178). Routledge.

Servant-Miklos, V., 2020. Problem-oriented project work and problem-based learning: "Mind the gap!". *Interdisciplinary Journal of Problem-Based Learning*, 14(1).

Ulger, K., 2018. The effect of problem-based learning on the creative thinking and critical thinking disposition of students in visual arts education. *Interdisciplinary journal of problem-based learning*, 12(1).

Smart Infrastructure For A Digital Ghana: Leveraging Drone Technology And E-Malls To Expand E-Commerce

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ABSTRACT:

E-commerce plays a significant role in driving economic development by expanding market access, promoting entrepreneurship, and creating jobs. It allows businesses, especially small and medium-sized enterprises, to reach global customers with lower operational costs. This digital shift boosts productivity, encourages innovation, and increases consumer choice. In developing regions, e-commerce also supports financial inclusion and the growth of digital infrastructure, further stimulating economic progress. This research investigates the evolving landscape of online shopping and e-commerce, alongside the operational and spatial dynamics of e-commerce and drone delivery services. Utilizing a mixed-methods approach, quantitative data were gathered through a questionnaire administered to e-commerce platform users, while qualitative insights were derived from interviews with industry professionals and case studies of operational facilities used by an e-commerce service provider and a leading drone delivery company in Ghana. The study reveals a steady upward trajectory in e-commerce activities, with a notable preference among users for door-delivery services over self-pickup options. Moreover, the research highlights key strategies for the design of cross-company drone delivery terminals, emphasizing scalability, adaptability, sustainable design principles, and the integration of barrier-free design features. Synthesizing quantitative and qualitative data, this study contributes to a deeper understanding of the spatial and operational requirements necessary for the design of UAV delivery terminals. It underscores the significance of durability, sustainability, and seamless integration of human-machine interactions in the design process, offering valuable insights for stakeholders involved in the development of future cross-company drone delivery infrastructure.

KEYWORDS: E-commerce, Unmanned Aerial Vehicles, Last-Mile-Delivery, Terminal

1. Introduction

Drones, also known as Unmanned Aerial Vehicles (UAVs), have great potential to transform delivery services, especially in logistics and e-commerce. These technologies are opening up new ways to handle deliveries more efficiently, particularly in areas where infrastructure is limited.

In countries like Ghana, where e-commerce is growing fast, delivering goods to rural and semi-urban areas remains a major challenge. With Zipline's success in using drones for medical deliveries and the growing presence in online shopping, there is an opportunity to combine their strengths for better service.

Despite the technological progress, there has been little focus on the architectural design of UAV delivery terminals that support different companies. This research addresses this gap by exploring architectural and operational requirements for designing cross-company drone delivery terminals. The overarching aim is to develop a scalable, sustainable, and barrier-free terminal prototype that can support seamless UAV logistics for multiple e-commerce and health service operators.

The study was guided by four research questions:

1. What are the current trends in online shopping and e-commerce?
2. How do drone delivery services and e-commerce platforms operate?
3. What are the spatial and operational needs of UAV delivery terminals?
4. How can a facility be designed to support cross-company UAV operations?

This study used an action research approach within a pragmatic framework to collect and analyse data from case studies, interviews, and surveys. A mixed-methods approach allowed both detailed insights and broader trends to be explored using thematic analysis and descriptive statistics. The research was focused in Kumasi and involved e-commerce users and industry stakeholders with a specific focus on and experience in e-commerce and UAV logistics.

The significance of this research lies in defining design strategies tailored to developing economies, integrating sustainability, scalability, and socio-cultural responsiveness, particularly in the Ghanaian setting. Key findings pointed to weak regulatory frameworks and highlighted the need for better integration of UAV systems into the built environment..

Literature Review

2.1 Introduction to and Significance of E-commerce/ Online Shopping to Economies

Online shopping is the process of purchasing goods or services from a seller over the internet using a web browser or a mobile app (Agyapong, 2018). E-commerce specifically deals with the use of specialised websites that host various retailers (Costa & Castro, 2021). Consumers can find a product of interest by visiting the website of the retailer directly or by searching among alternative vendors using a shopping search engine, which displays the same product's availability and pricing at different e-retailers (Agyapong, 2018). A typical online store enables the customer to browse the firm's range of products and services and view photos or images of the products, along with information about the product specifications, features, and prices (Zhao, et al., 2016). Typically, For physical products, the e-tailer ships the products to the customer (Venkatesh et al., 2020) after the order is placed.

In recent times, online shopping has had significant economic and business impacts. Online shopping sales in 2020 surged nearly 22% to hit a new record, with consumers spending \$6.3 million per minute online (Costa & Castro, 2021). As consumers increasingly turn to digital platforms for their purchasing needs, the economic landscape undergoes significant transformations (Alzoubi et al., 2022). Key among these impacts are ; the substantial migration of consumers from physical stores to e-commerce platforms (Gajewska et al., 2021), a transition which has prompted businesses to adapt their strategies to meet the evolving demands of a digital marketplace. Also, e-commerce has created new business opportunities, particularly for small and medium-sized enterprises, by providing them with a platform to reach a wider audience and sell their products globally (Costa & Castro, 2021), removing major limits faced by traditional physical stores and creating a larger global economy. Moreover, the rise of online shopping has contributed to the globalization of markets. E-commerce facilitates cross-border transactions, enabling consumers to purchase products from international vendors with ease (Alzoubi et al., 2022). Additionally, online shopping has led to increased competition among retailers, resulting in lower prices for consumers (Atta Mills & Baafi, 2021).

This globalization has both advantages and challenges for businesses. While it provides new market opportunities, it also requires companies to navigate complex logistical and regulatory landscapes (Peprah et al., 2022). Online shopping has also had negative impacts, such as the closure of physical stores and the loss of jobs in the retail sector. Furthermore, online shopping has led to concerns about data privacy and security, as well as the environmental impact of increased packaging and shipping (Pobee, 2021).

From a business perspective, the impact of online shopping is multifaceted. Established e-commerce giants have not only redefined retail but have also become major economic players, influencing stock markets and reshaping industry landscapes (Peprah et al., 2022). Small and medium-sized enterprises (SMEs) have leveraged online platforms to reach a global audience, but they also face challenges related to competition and digital marketing (Manyanga, Makanyeza, & Muranda, 2022). Additionally, the demand for advanced technologies in online retail, such as artificial intelligence and data analytics, has spurred innovation and investment, creating new opportunities for tech-driven business models (Manyanga et al., 2022).

2.2 Trends in E-Commerce

Online shopping has experienced exponential growth, with global sales projected to surpass \$6.5 trillion by the end of 2023, accounting for more than 20% of total retail sales (Alzoubi et al., 2022). One notable trend is the surge in mobile commerce, where consumers increasingly prefer shopping through their smartphones and tablets, driven by the ubiquity of mobile devices, improved internet connectivity, and user-friendly mobile applications (Antwi et al., 2020). Consumers now expect 24/7 accessibility, personalized recommendations, and hassle-free returns, challenging traditional retailers to adapt to meet these changing demands to remain competitive (Geng, Wang, Chen, Song, & Yu, 2019).

Another significant trend is the rise of social commerce, where social media and online shopping are integrated. Businesses are leveraging social media to reach a wider audience and sell their products directly to consumers, sometimes through influencers (Geng et al., 2019). Platforms like Instagram, Facebook, and Pinterest have integrated shopping features, allowing users to discover and purchase products directly within the social media interface.

Additionally, consumers are increasingly concerned about the environmental impact of online shopping, leading to a growing trend towards sustainable and eco-friendly products and packaging. E-commerce platforms are responding by providing transparent information about the sourcing and manufacturing pro-

cesses of products, and there is a growing market for sustainable and eco-friendly products (Gajewska et al., 2021).

2.3 Courier/Delivery Services and their role in the e-commerce industry

Courier services are best described transportation of goods, information or services with a focus on their fastest possible delivery, reliability and convenience (Mycnar, 2021). Classification of the courier services depends on the nature of the delivery; for example, there are air couriers, ground couriers, sea couriers, and rail couriers. The main types of courier services include domestic courier services, international courier services, same-day courier services, and last-mile delivery services (Yao-Hung & Yon-Chun, 2013). Courier services provide a faster and safer way that many other types of businesses depend on to transport their parcels and products (Brown et al., 2008).

Service delivery and courier services comprise varied sub-sectors. Each has its function and characteristics that span from local parcel distribution; to specialized ones for industries like medicament or perishables (Mohd et al., 2019). The courier services market is segmented based on service type, destination, end use, and region: There are three service types which are; B2B, B2C as well and C2C and two kinds of destinations namely; local and foreign (Gulc, 2021). Specific industries include but are not limited to; healthcare and pharmaceutical delivery, food and grocery delivery, specialty and sensitive cargo delivery, domestic courier services, and international courier services

2.4 Mode of Operation of Modern Day Last-Mile Delivery Services

Last-mile delivery, which generally refers to the final mode of delivery of goods and services to the consumer, is usually the most critical part of the delivery process. It is the final step in the delivery cycle, and is usually costly and complex. (Engesser et al., 2023). Delivering orders in a city or suburb is a very challenging issue for courier services. Courier companies encounter many difficulties in last-mile deliveries including equipment failure, traffic jams, poor directions to destination etc (Engesser et al., 2023).

The mode of operation of courier services comes in various stages: pickup, sorting and shipping, tracking and finally, delivering it. Couriers collect packages directly from the company or seller, and then they either deliver the orders to clients, or hold the items in their holding centres and wait for self-pickup by the customer (Bel et al., 2014). Companies may have to incorporate multiple modes in the fulfil-

ment of orders depending on the transport costs and distribution. Many courier companies have started using large vehicles for moving the goods from point A to B while distributing them at a small distance inside local areas by means other than automobiles (e.g., bicycles or minivans).

The process of e-commerce operations works with the following key elements in a step-by-step process; Order Placement; Payment; Pickup; Transportation; Sorting and Routing; Tracking and Monitoring; Delivery; Payment (if not done at second stage); Proof of Delivery; Return or Redelivery; Customer Feedback and Support (Shah et al., 2019). Currently, companies are upgrading their services to satisfy customer demands by using GPS tracking systems to keep consumers updated on where exactly their products are (Gramatikova, 2019).

2.5 Technological Advancements in Courier Services

The arrival of the internet and digital technologies have greatly affected service delivery. The advent of e-commerce necessitated fast and reliable delivery systems for online platforms, where they have to be able to deliver goods quickly for consumers (CLMI, 2023). The development of these changes has forced companies to invest in technological advances such as unmanned vehicles or drones for last-mile deliveries that can be reliable and prompt enough to satisfy the increasing need for fast and safe shipments (Gruber et al., 2014).

Technological advancements, changes in the economy and evolving global trends propel a constant reshaping of consumer needs which leads to changes and enhancements in the courier services and service delivery industry (Shah et al., 2019). Drones and autonomous vehicles, e-commerce integration, real-time tracking, same-day and instant delivery solutions, last-mile delivery solutions, crowdsourced delivery and subscription services, data analytics, and sustainability initiatives (Lin et al., 2019) are some of the key advancements to modern courier services.

This has had a lot of impacts on economic development. Goods and services are moved quickly as well as effectively for improved organizational output and performance (Yao-Hung & Yon-Chun, 2013). Local job creation boosts local economies, more money is invested into research and development which in turn also leads to more efficient delivery systems. Courier services ensure that products get to their customers on time; this builds trust in the marketplace and increases customer satisfaction (Jackson, 2023). This is also very important for the overall customer

experience, as it decides whether it will be repeat business and whether further purchases are made by the customer or not.

The service delivery includes various areas such as health care, education, tourism, and professional services among others (Fernandes et al., 2017). They create jobs in the country and contribute towards economic growth through the generation of income and taxes as well (Fernandes et al., 2017).

Even with all these advancements, the industry still faces certain challenges; Seasonal peaks and demand fluctuations (Bel et al., 2014), Damage to items, Sustainability and environmental concerns (Chen et al., 2022), Labour costs and availability (Darbyshire, 2008), Last-mile delivery challenges (Engesser et al., 2023), Global and cross-border challenges (Siahaan et al., 2023), Data security and privacy (Kougiannou & Mendonça, 2021), and reverse logistics or unwanted item return (Allen & Zhang, 2019) are the major challenges faced within the industry.

2.6 The Way Forward

With advancements in technology and changing consumer preferences, the traditional methods of courier services are being challenged (Gramatikova, 2019). To meet the growing demand and provide efficient delivery solutions, courier companies are adopting new strategies, modes, and tools. These include the use of drones for delivery, advanced tracking systems, and automated sorting facilities (Hausmann et al., 2019).

There are several consensus projections, modes, methods and tools that are predicted to shape the industry, key among these is the use of Autonomous vehicles and Technology (Aljohani & Thompson, 2020). Other innovations include Data-driven logistics (Xiang & Zheng, 2014), Rapid integration of sustainability and circular economy principles, (Frachtenberg, 2019), sustainable and eco-friendly solutions (Voigt & Kuhn, 2021), and Customer-centric technologies (Jinhui, 2014).

2.7 Unmanned Aerial Vehicles and Their Application in Courier/ Delivery Services

Drone technology and unmanned aerial vehicles (UAVs) have revolutionized various industries and are becoming increasingly popular worldwide (Chan et al., 2018). One of the key advantages of drones is their ability to reach places that are difficult or dangerous for humans to access. They can fly at different altitudes, navigate

through challenging terrains, and collect data or capture images in real-time (Bello et al., 2022). Companies have been testing drone deliveries, aiming to expedite the transportation of goods and reduce delivery times (Raivi et al., 2023). Drones can navigate through traffic-free airspace, avoiding road congestion and reaching remote or inaccessible locations, making them ideal for urgent or emergency deliveries (Green et al., 2020).

Unmanned aerial vehicles can be classified based on their mode of operation (Gharibi et al., 2021). They are either autonomous or manually controlled (Chung et al., 2020). The most common types of drones are multi-rotor drones and fixed-wing drones (Menkhoff et al., 2016). Other types are also considered, such as single-rotor drones, fixed-wing hybrid drones, powered-lift drones, helicopter drones, commercial drones, tactical drones, and eVTOL aircraft (Li et al., 2023). For courier services, the two main types used are fixed wing drones and multi-rotor drones. Fixed wing drones for long distances (Li et al., 2023), and multi-rotor drones for shorter distances (Menkhoff et al., 2016).

Drones are becoming increasingly popular for courier and delivery services due to their efficiency and cost-effectiveness (Jones, 2017). Drones are more cost-effective than traditional express delivery methods, costing around \$1.23 per delivery compared to \$5.33 for a four-mile distance by traditional delivery methods (Lin et al., 2020). Using electric, autonomous drones for package deliveries can result in operational costs which are at least 70% lower than a van delivery service. Compared to traditional delivery vehicles, drone delivery service offers reduced operational costs, as drones consume less energy and require less maintenance (Wang et al., 2020).

2.8 Public Perception Towards Drones and Unmanned Aerial Vehicle Technology

The attitude of people towards drones and UAV technology is diverse and can vary based on several factors, including personal experiences, cultural perspectives, industry involvement, and regulatory considerations (Jeong et al., 2019). One significant concern among the public is related to privacy (Telli et al., 2023). The potential of drones equipped with cameras to intrude on personal privacy or conduct unauthorized surveillance raises apprehensions. There are debates about legislation and regulations needed to safeguard privacy rights while ensuring responsible drone use. There are also legitimate concerns about the safety aspects of drones.

Incidents involving drones flying in restricted areas, near airports, or causing potential hazards have raised public concerns about accidents or collisions (Jeong et al., 2019).

Businesses and industries generally view drones as valuable tools for enhancing efficiency, reducing operational costs, and expanding capabilities. Companies involved in logistics, agriculture, construction, and infrastructure inspections often embrace the technology for its potential to improve their services (Li et al., 2023). As drones become more integrated into daily life and offer solutions that benefit society, people are gradually accepting and adapting to the presence of these technologies. Familiarity and understanding often lead to increased acceptance (Lin et al., 2020).

3. Research Methodology

This research was guided by a pragmatic worldview, which values practical solutions and context-based understanding. Pragmatism allowed the researchers to adapt their methods to changing situations and focus on real-world experiences during data collection. An action research approach was used to work closely with stakeholders like Zipline, Jumia, and e-commerce users. This helped improve understanding and design strategies through feedback and collaboration as the research progressed.

A mixed-methods design combined interviews with key stakeholders and questionnaires for regular e-commerce users. This blend of qualitative and quantitative data helped capture both personal experiences and measurable trends in UAV delivery and logistics.

Participants were chosen based on their experience with e-commerce platform usage, and site visits were conducted at Zipline's Mpanya facility and Jumia's Kumi centre. The data was analysed using themes and statistics, with strong results despite some limits in data access and interview availability. These insights supported the development of the proposed terminal design. While the methodology offered comprehensive insights, certain limitations were experienced. Access to proprietary data was restricted in some cases, and not all stakeholders were available for in-person interviews. Nevertheless, the data collected was sufficient to inform both the research objectives and the terminal design framework proposed.

4. Findings and Discussion

The analysis for this research revealed several critical themes influencing the feasibility and design of cross company UAV delivery terminals in Ghana. Key findings are drawn from stakeholder interviews, user surveys, and case studies conducted at Zipline's Mpanya facility and Jumia's Kumasi holding and distribution centre.

Respondents to the survey were users of Jumia Ghana (in Kumasi), a UAV engineer at Zipline Inc., and the facilities associate manager at Jumia Ghana. Out of 30 distributed questionnaires, 22 responses were received, yielding a 73% response rate. This robust sample size provided credible insights into consumer behaviour and delivery preferences in Kumasi. The expert interviews achieved a 100% response rate and offered rich qualitative data regarding operational needs and facility design considerations.

4.1 Consumer Preferences

The results of the survey showed that female respondents preferred door deliveries, while the males were more likely to choose self-pickup. Employment status also influenced preferences; working individuals and most students chose door-delivery for its convenience, whereas unemployed people and some students opted for self-pickup. Younger consumers showed a strong preference for online shopping and door delivery over physical stores and self-pickup.

However, many users were dissatisfied with current last-mile delivery services. Complaints included poor address systems, delivery delays due to traffic, and inconsistent service quality. These issues highlight the need for improved solutions, such as drones, which could offer faster and more reliable deliveries.

Over 70% of respondents said they were open to drone-based deliveries, attracted by speed and convenience. Still, they raised concerns about safety, delivery accuracy, and privacy. Many also called for clearer regulations and more public education on drone usage in cities.

4.2 Growth Of E-Commerce

The Ghanaian e-commerce sector is expanding, driven by smartphone penetration, mobile money, and internet access. Despite this, infrastructure challenges and trust issues still affect adoption rates. The e-commerce market in Ghana has experienced significant growth in recent years. Data presented to the researcher from Jumia Ghana indicated the value of the e-commerce market in Ghana reached \$547 million in 2020 representing a 37% increase from the previous year.

This growth can be attributed to various factors including increased internet penetration, improved mobile payment systems (mobile money services, Flexipay etc) and the expansion of e-commerce platforms.

E-commerce infrastructure still remains underdeveloped as is. Issues such as poor road networks, inconsistent electricity supply, and weak digital addressing systems hinder seamless delivery. These challenges create an opportunity for aerial delivery systems to bridge the efficiency gap.

4.3 Operational Insights of Drone Delivery & E-Commerce Companies

4.3.1 Zipline Inc.

Zipline International Inc. is an American company that designs, manufactures, and operates delivery drones. The company operates distribution centres across seven countries in three continents – Asia, Africa, And North America. As of November 2023, its drones had made more than 800,000 commercial deliveries and flown more than 40 million autonomous miles. In Ghana, Zipline’s drones deliver medical products, including blood, vaccines, infusions, and common medical commodities.

Their operations are largely semi-automated: drones are launched from a rig, fly autonomously, and drop packages via parachute at designated points. Battery charging and maintenance are conducted onsite at dedicated bays. Their current operations involve the use of fixed-wing drones to deliver medical supplies to health facilities on request, with a range of up to 80 kilometres. However, they have multi-rotor drones in development to be adopted for last-mile courier services with e-commerce platforms. Expert feedback emphasized reliability, speed, and independence from road networks as key advantages to their operations.

However, they face certain challenges such as; Regulatory barriers, especially restrictions on beyond-visual-line-of-sight (BVLOS) operations, the need for public education to increase acceptance, and airspace congestion in urban settings (conflicts with regulatory bodies like Ghana Aviation Authority and National Security Agencies).

4.3.2 Jumia Ghana

Jumia currently operates on a hub-and-spoke distribution model. Orders are placed online by costumers and then fulfilled through centralized sorting and distribution centers, after which last-mile couriers and courier deliver goods to customers. Alternatively, customers can opt for self-pickup.

Jumia highlighted interest in adopting UAV technology, particularly for express

deliveries and accessing traffic-congested and remote zones. However, certain challenges with integration were noted, such as ensuring drone drop-off zones align with the locations specified by the customers, and circumnavigating restricted airspace and the regulatory framework around and within the city (Kumasi). The transition to UAV logistics would require not only physical infrastructure but also policy frameworks to support operations within Kumasi and Ghana.

4.4 Infrastructural Requirements in the Design of a Facility for Cross-Company Drone Delivery

Two case studies, Zipline's Mpanya drone distribution center and Jumia's Amakom holding facility, were examined to identify operational and spatial requirements needed to facilitate cross-company drone delivery. This was done to ascertain the key logistical and infrastructural developments that would enhance the operations of both companies without any interferences between the two, while still ensuring maximum efficiency.

From the case studies, the key infrastructural needs for UAV delivery terminals include:

- Launch and landing pads which should be kept open, obstacle-free areas equipped with safety perimeters and wind-resilient surfaces.
- Drone Maintenance and Charging Bays: Located near launch sites for convenience.
- Secure Storage Areas: The facility to be designed should have segregated zones for inbound and outbound parcels with real-time inventory management.
- Control Rooms and IT Infrastructure for monitoring flights, coordinating logistics, and managing user interfaces.
- Staff Welfare Areas like offices, restrooms, and break rooms for operational staff.
- Spatial Layouts and Human Interaction Zones

Both Zipline and Jumia facilities reflect the necessity of maintaining clear separations between UAV operations and human-centric spaces. For instance, the Zipline facility isolates drone movement zones from visitor waiting areas to ensure safety. Similarly, the Jumia warehouse includes demarcated loading and unloading bays, each with limited human interaction. These practices inform a core principle of UAV

terminal design: segregating mechanical operations from public access. The inclusion of visual signage, QR code-based retrieval systems, and automated check-ins are recommended to streamline interactions and minimize risks.

Design Recommendations from industry experts and included architectural principles such as modularity, integration of hybrid facilities combining parcel sorting, storage, and UAV launch areas, expandability, incorporation renewable and backup energy systems, especially solar, to ensure off-grid capabilities, using lightweight, corrosion-resistant materials like aluminum and fiber-reinforced composites to withstand environmental and operational stress, etc.

Selection of an appropriate site to locate the facility to be designed is also key. A key factor insite selection is the catchment area between the facility and areas of business, residences, and offices.

5. Conclusion and Further Research

The purpose of this study was to investigate the operational and logistical difficulties associated with incorporating unmanned aerial vehicles (UAVs) into e-commerce. The research employed a mixed-methods approach, combining expert interviews from the drone and e-commerce sectors with surveys of online customers.

Results indicate that Ghanaian consumers are increasingly shopping online and favor door delivery over self-pickup. According to the research, Zipline and Jumia have different logistical requirements that need to be balanced in a shared delivery facility. Secure landing areas, reliable power supplies, and weather-resistant materials were some key criteria for drone terminals, whereas scalability, storage effectiveness, and accessibility were some of the spatial requirements.

6. Recommendations

Based on the findings from the study, the following recommendations were made;

1. Conduct further research into online shopping trends to stay informed about changing consumer habits and market trends.
2. Investigate how stakeholder partnerships in the drone delivery sector can improve both operational performance and service quality.
3. Study how new technologies affect UAV terminal design to meet current standards and practices.
4. Design facilities that can grow easily and adapt to future technological and operational changes.

For a sustainable architectural practice to be achieved in a mid-income country such as Ghana, the following cyber-architectonic recommendations are needed: The study offers a useful foundation to guide the architectural design of cross-company drone delivery terminals. Architects, urban planners, logistics firms, and legislators interested in next-generation delivery systems will find its results especially helpful. To promote drone logistics in Ghana, recommendations include the need for better public infrastructure and regulatory laws. More research is recommended on the socio-economic impact of drone deliveries on local economies in the Ghanaian context, and further development of digital mapping and digital address infrastructure.

References

- Aljohani, K., & Thompson, R. (2020). An Examination of Last Mile Delivery Practices of Freight Carriers Servicing Business Receivers in Inner-City Areas. *Sustainability*. <https://doi.org/10.3390/su12072837>.
- Alkouz, B., Bouguettaya, A., & Mistry, S. (2020). "Swarm-based drone-as-a-service (SDaaS) for delivery,". 2020 IEEE International Conference on Web Services (ICWS) [Preprint]. Available at: <https://doi.org/10.1109/icws49710.2020.00065>.
- Allen, J., & Zhang, A. (2019). E-commerce and the logistics industry in the UK: a scoping study. *Supply Chain Management*, 24(1), 93-111.
- Alzoubi, H., Alshurideh, M., Al Kurdi, B., Alhyasat, K., & Ghazal, T. (2022). The effect of e-payment and online shopping on sales growth: Evidence from banking industry. *International Journal of Data and Network Science* doi: 10.5267/j.ijdns.2022.5.014 .
- Antwi, S., Agyemang Ameyaw, M., & Adamu, M. (2020). What Drives Online Shopping Among Tertiary Students in Ghana: The Role of Attitude and Subjective Norm. *Journal of Applied Management and Advanced Research*, Volume 2, Issue No 2 (July-December 2020) Available at: www.imperialpublications.com DOI: 10.34047/JAMAR.2020.v02i01.005.
- Atta Mills, E., & Baafi, M. (2021). How And Where Do We Dispose of Hardware Enablers of E-Commerce A Case Study of Accra, Ghana. *Management and Economics (ICEME 2021)*, July 17–19, 2021, Beijing, China. ACM, New York, NY, USA, 6 pages. <https://doi.org/10.1145/3481127.3481230>.

- Bel, G., Brown, T., & Warner, M. (2014). Editorial Overview: Symposium on Mixed and Hybrid Models of Public Service Delivery. *International Public Management Journal*, 17, pp. 297 - 307. <https://doi.org/10.1080/10967494.2014.935231>.
- Bello, A., Navarro, F., Raposo, J., Miranda, M., Zazo, A., & Álvarez, M. (2022). Fixed-Wing UAV Flight Operation under Harsh Weather Conditions: A Case Study in Livingston Island Glaciers, Antarctica. *Drones* 2022, 6, 384. <https://doi.org/10.3390/drones6120384>.
- Brown, T., Potoski, M., & Van Slyke, D. (2008). Changing Modes of Service Delivery: How Past Choices Structure Future Choices. *Environment and Planning C: Government and Policy*, 26(1), 127-143. <https://doi.org/10.1068/c0633>.
- Chan, K., Nirmal, U., & Cheaw, W. (2018). Progress on drone technology and their applications: A comprehensive review. *AIP Conference Proceedings*.
- Chen, C., Leon, S., & Ractham, P. (2022). "Will customers adopt last-mile drone delivery services? an analysis of drone delivery in the emerging market economy,". *Cogent Business & Management*, 9(1). Available at: <https://doi.org/10.1080/23311975.2022.2074340>.
- Chung, S., Sah, B., & Lee, J. (2020). Optimization for drone and drone-truck combined operations: A review of the state of the art and future directions. *Computers and Operations Research*.
- CLMI. (2023). 5 Trends Shaping the Future of Courier & Logistics. | LinkedIn, Overcoming Challenges in the Courier Industry: Strategies for Success. Available at: <https://www.linkedin.com/> (Accessed: 19 October 2023). . Courier and Logistics Management Institute.
- Costa, J., & Castro, R. (2021). SMEs Must Go Online—E-Commerce as an Escape Hatch for Resilience and Survivability. *Journal of Theoretical and Applied Electronic Commerce Research* 2021, 16, 3043–3062. <https://doi.org/10.3390/jtaer16070166>.
- Manyanga, W., Makanyeza, C., & Muranda, Z. (2022). The effect of customer experience, customer satisfaction and word of mouth intention on customer loyalty: The moderating role of consumer demographics. *Cogent Business & Management*, 9:1,2082015, DOI: 10.1080/23311975.2022.2082015.
- Menkhoff, T., Tan, E., Ning, K., Hup, T., & Pan, G. (2016). Tapping Drone Technology To Acquire 21st Century Skills: A Smart City Approach.
- Mohd, A., Rozeha, A., Abdul-Hadi, R., & Abdul Hamid, F. (2019). Development of

android-based apps for courier service management. Indonesian Journal of Electrical Engineering and Computer Science, Available from: 10.11591/IJEECS.V15.I2.PP1027-1036. Development of android-based apps for courier service management. Indonesian Journal of Electrical Engineering and Computer Science, Available from: 10.11591/IJEECS.V15.I2.PP1027-1036.

Myncar, H. (2021). What are the different types of courier services? Mobile One Courier | Same-Day Delivery Business Solutions. Available at: <https://mobileone-courier.com/types-of-courier-services/> (Accessed: 19 October 2023).

Peprah, A., Giachetti, C., Møller Larsen, M., & Rajwani, T. (2022). How Business Models Evolve in Weak Institutional Environments. The Case of Jumia, the Amazon.com of Africa. *Organization Science*, 33(1), 431-463. <https://doi.org/10.1287/orsc.2021.1444>.

Raivi, A., Huda, S., Alam, M., & Moh, S. (2023). Drone Routing for Drone-Based Delivery Systems: A Review of Trajectory Planning, Charging, and Security. *Sensors* 2023, 23, 1463. <https://doi.org/10.3390/s23031463>.

Shah, H., Lunia, H., Bagaria, I., Shah, J., & Killa, K. (2019). Operations research in courier delivery service trends. *International Journal of Advance Research, Ideas and Innovations in Technology*.

Siahaan, R., Sinaulan, R., & Ismed, M. (2023). "Legal Responsibility For The Role Of Online Transportation Courier Services In Drug Trafficking", Policy, Law, Notary And Regulatory Issues, 2(1), pp. 52–66. doi: 10.55047/polri.v2i1.530.

Telli, K., Kraa, O., Himeur, Y., Ouamane, A., Boumehraz, M., Atalla, S., & Mansoor, W. (2023). A Comprehensive Review of Recent Research Trends on UAVs. *Energy Systems Modelling (MSE) Laboratory, Mohamed Khider University, Biskra, Algeria* arXiv:2307.13691v1 [cs.RO].

Venkatesh, V., Speier-Pero, C., & Schuetz, S. (2020). Why do people shop online? A comprehensive framework of consumers' online shopping intentions and behaviors. *Information Technology & People* Vol. 35 No. 5, 2022 pp. 1590-1620 © Emerald Publishing Limited 0959-3845 DOI 10.1108/ITP-12-2020-0867.

Voigt, S., & Kuhn, H. (2021). Crowdsourced logistics: The pickup and delivery problem with transshipments and occasional drivers. *Networks*, 79, pp. 403 - 426.

Wang, K., Yuan, B., Zhao, M., & Lu, Y. (2020). Cooperative route planning for the drone and truck in delivery services: A bi-objective optimisation approach. *Journal of the Operational Research Society*, 71:10, 1657-1674,

Xiang, Y., & Zheng, H. (2014). Method for courier to deliver package through self-help delivery equipment. Method for courier to deliver package through self-help delivery equipment.

Yao-Hung, C., & Yon-Chun, C. (2013). Courier Collaboration in Pickup and Delivery Services by Hub Transshipment across Flexible Time Periods. *International journal of information and management sciences*, 24(4), 363-380. Available from: 10.6186/IJIMS.2013.24.4.6.

Zhao, W., Li, S., He, Y., Chang, E., Wen, J.-R., & Li, X. (2016). Connecting Social Media to E-Commerce Cold-Start Product Recommendation Using Microblogging Information. *Ieee Transactions On Knowledge And Data Engineering*, Vol.28, No.5, May 2016.

Engesser, V., Rombaut, E., Vanhaverbeke, L., & Lebeau, P. (2023). Autonomous Delivery Solutions for Last-Mile Logistics Operations: A Literature Review and Research Agenda *Sustainability* 2023, 15, 2774. <https://doi.org/10.3390/su15032774>. Sustainability <https://www.mdpi.com/journal/sustainability>.

Fernandes, A., Tulsyan, A., Nisar, A., Rawat, A., & Kumar, A. (2017). Use of operations research in courier delivery services. *International Journal of New Technology and Research*, 3(10), p.263222.

Frachtenberg, E. (2019). Practical Drone Delivery. *IEEE Xplore: TECHNOLOGY PREDICTIONS*.

Gajewska, T., Zimon, D., Kaczor, G., & Madzić, P. (2021). The Impact of The Level of Customer Satisfaction on The Quality of E-Commerce Services. *International Journal of Productivity and Performance Management* Vol. 69 No. 4, 2020 pp. 666-684 ©Emerald Publishing Limited 1741-0401 DOI 10.1108/IJPPM-01-2019-0018.

Geng, R., Wang, S., Chen, X., Song, D., & Yu, J. (2019). Content Marketing in E-Commerce Platforms in The Internet Celebrity Economy. *Industrial Management & Data Systems* Vol. 120 No. 3, 2020 pp. 464-485 ©Emerald Publishing Limited 0263-5577 DOI 10.1108/IMDS-05-2019-0270.

Gharibi, M., Gharibi, Z., Boutaba, R., & Waslander, S. (2021). A Density-Based and Lane-Free Microscopic Traffic Flow Model Applied to Unmanned Aerial Vehicles. *MDPI Drones*, 5, 116. <https://doi.org/>.

- Gramatikova, E. (2019). Trends in Courier Services in Terms of Digitalization of Commerce. JOURNAL OF THE UNION OF SCIENTISTS - VARNNA, ECONOMIC SCIENCES SERIES, 8(3), 17-27. Available from: 10.36997/IJUSV-ESS/2019.8.3.17.
- Green, D., Karachok, A., & Gregory, B. (2020). The Potential of Drone Technology in Pandemics.
- Gruber, J., Kihm, A., & Lenz, B. (2014). A new vehicle for urban freight? An ex-ante evaluation of electric cargo bikes in courier services. Research in transportation business and management, 11, pp. 53-62. <https://doi.org/10.1016/J.RTBM.2014.03.004>.
- Gulc, A. (2021). Multi-stakeholder perspective of courier service quality in B2C e-commerce PLoS ONE 16(5): e0251728. <https://doi.org/10.1371/journal.pone.0251728>. PLOS ONE.
- Hausmann, L., Murnane, J., Mundra, N., & Neuhaus, F. (2019). The-Next-Normal-The future-of-parcel-delivery-vF. Global Editorial Services Copyright © 2019 McKinsey & Company.
- Jeong, H., Song, B., & Lee, S. (2019). Truck-drone hybrid delivery routing: Payload-energy dependency and No-Fly zones. International Journal of Production Economics.
- Jinhui, D. (2014). Selection and Evaluation of Express Delivery (International Conference on Logistics Engineering, Management and Computer Science (LEMCS 2014)).
- Jones, T. (2017). "International Commercial Drone Regulation and drone delivery services.". Available at: <https://doi.org/10.7249/rr1718.3>.
- Li, X., Tupayachi, J., Sharmin, A., & Ferguson, M. (2023). Drone-Aided Delivery Methods, Challenge, and the Future: A Methodological Review. Drones 2023, 7, 191. <https://doi.org/10.3390/drones7030191>.
- Lin, B., Zhao, Y., & Lin, R. (2019). Optimization for courier delivery service network design based on frequency delay. European Journal of Operational Research.
- Lin, M., Lyu, J.-Y., Gao, J.-J., & Li, L.-Y. (2020). Model and Hybrid Algorithm of Collaborative Distribution System with Multiple Drones and a Truck. Hindawi Scientific Programming Volume 2020, Article ID 8887057, 16 pages <https://doi.org/10.1155/2020/8887057>.

Cloud Computing Adoption And Impact On SMES Performance

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ABSTRACT:

The traditional business processes in recent times have been shaped by the advent of digital transformations. The advent of digital transformation is breathing new life into the business startup scene through the integration of advanced technologies such as cloud computing, artificial intelligence, blockchain and big data into their essential business operations. The successful integration boosts productivity in the workplace while also providing aspiring entrepreneurs with the practical skills and strategic insights they need to thrive and compete in ever-changing markets (Corvello et al., 2022). Startups, usually facing constraints in resources and a strong desire for quick growth, have a great chance to boost their scaling and improve operational efficiency through the smart use of digital technologies such as cloud computing and AI Kuteesa et.al., 2024).

Nonetheless, there have been little to no engage or education on this subject. This paper seeks to highlight the digital transformation in startups and the potential advantages it holds for future entrepreneurs as an initial step in addressing this gap. The study focuses on key small and medium-scale entrepreneurs (startups). The research utilised a quantitative approach. Next, a survey questionnaire was utilised to gather responses from the target population. The findings of the study indicate that, that startups that thoughtfully embrace digital transformation from the start can experience much quicker growth than those that stick to conventional methods. This highlights the essential importance of digital strategies, not just as a benefit, but as a possible driver for initial success and on-going competitiveness in the market.

KEYWORDS: Digital transformation, SMEs, Cloud computing, Diffusion of Innovation, Firm size, Technology Readiness

1. Introduction

The advent of cloud computing has fundamentally transformed the landscape of information technology services, revolutionizing development, distribution, scalability, maintenance, updates, and payment mechanisms (Marston et al., 2011). This paradigm shift represents a convergence of two critical IT trends: enhanced IT efficiency through optimal utilization of scalable hardware and software resources, and improved business agility enabling rapid deployment, parallel processing, and real-time responsive applications. Cloud computing offers virtualized and distributed resources including networks, servers, storage, applications, and services accessible through streamlined, flexible, and on-demand mechanisms that fundamentally alter how organizations access and utilize information and communication technology (ICT) to support their operations (Loukis, et al., 2017)

For SMEs, cloud computing represents a transformative opportunity to overcome traditional resource constraints. The pay-per-use model enables better IT resource management in response to fluctuating demand while minimizing capital expenditure requirements (Khayer et al., 2020). Given their typically limited IT budgets and technological competencies, SMEs have historically relied on external IT professionals to achieve their technological objectives. Cloud computing's on-demand service model offers these enterprises the ability to access sophisticated technologies and enhanced decision-making tools that can significantly impact their overall success and competitive positioning.

Despite extensive research on cloud computing technical aspects and large enterprise adoption patterns, limited attention has been devoted to SME adoption experiences, particularly in developing economies like Ghana (Gupta, et al., 2013). The institutional legacies and environmental factors specific to African contexts remain underexplored, creating opportunities for contextually relevant research contributions (Kshetri, 2010). This study addresses these gaps by examining cloud computing adoption and performance impacts among Ghanaian SMEs, providing insights into technology adoption patterns in emerging market contexts while contributing to the broader understanding of digital transformation and the education of entrepreneurs in developing economies.

2. Literature Review

2.1 Cloud Computing: Conceptual Foundation

Cloud computing represents a paradigm shift in computing architecture, providing dynamically scalable resources on demand through internet-based delivery mechanisms that combine service-oriented architecture (SOA) and virtualization techniques (Papazoglou, 2003). This technological transformation enables organizations to concentrate on core business activities while eliminating concerns about IT infrastructure management (Garrison, et al., 2012). By reducing infrastructure investment requirements, cloud computing creates a more equitable competitive landscape, providing organizations with innovative concepts but limited capital the opportunity to deploy applications and flourish (Berriman et al., 2013).

The cloud computing ecosystem encompasses multiple service delivery models that address diverse organizational requirements. Infrastructure as a Service (IaaS) provides virtualized computing resources including storage and processing capabilities, enabling the establishment of virtual data centers within cloud environments (Busch et al., 2014). Platform as a Service (PaaS) offers underlying hardware and operating system technologies, allowing users to deploy custom applications through virtual servers, file systems, and database management systems (Jamsa, 2013). Software as a Service (SaaS) delivers on-demand, web-based applications accessible through browsers without requiring local installation, offering convenience and global accessibility (Mazumdar, 2018).

Cloud deployment models further diversify implementation options based on usage scope and exclusivity requirements. Private clouds provide isolated networks with restricted access, enabling organizations to maintain strict data control while leveraging scalability and agility benefits (Gkikas, 2014). Public clouds offer third-party services accessible to general populations through internet connections, with infrastructure ownership residing with service providers (Magoulès et al., 2012). Hybrid clouds combine multiple deployment models through integrated technologies, enabling rapid migration between private and public environments based on capacity requirements (Mazumdar, 2018). Community clouds facilitate shared infrastructure among organizations with similar concerns, missions, or security standards (Govender, 2016).

2.2 Cloud Computing Adoption Drivers

The proliferation of cloud computing adoption stems from multiple technological and business drivers that address contemporary organizational challenges. Scalability emerges as a primary motivator, enabling businesses to expand operations

and technology capabilities while simultaneously reducing costs during economic downturns, contrasting with traditional in-house IT establishments requiring ongoing expenditures regardless of utilization levels (Khayer et al., 2020). Reliability considerations focus on ensuring consistent accessibility through distributed and parallel computing principles that revolutionize IT service provision (Berisha and Pula, 2017).

Elasticity represents an increasingly critical attribute for successful systems in commercial and administrative contexts, providing unprecedented resource flexibility that enables organizations to dynamically adjust computing power and resource allocation based on demand fluctuations (Khayer et al., 2020). High resilience capabilities offer autonomous disaster recovery and restoration functions through centralized cloud resources, with some organizations employing internal cloud models as public cloud backups to enhance operational flexibility (Magoulès et al., 2012). Facility consolidation through centralized storage services provides potential cost savings compared to local service provision, with resource sharing enabling reduced operational expenses while maintaining universal access to shared data and robust recovery capabilities (Mazumdar, 2018).

2.3 Small and Medium-sized Enterprises (SMEs): Characteristics and Challenges

SMEs represent critical economic engines across global economies, yet definitional inconsistencies persist across different countries and contexts. The Ghana Statistical Service defines SMEs based on employee numbers, encompassing microenterprises (fewer than five full-time employees), small businesses (5-30 employees), medium-sized businesses (31-100 employees), with larger enterprises exceeding 100 employees (Bediako-kyeremeh et al., 2019). These enterprises exhibit distinctive characteristics including combined ownership and management structures, specialized product focus, gradual growth patterns, resource limitations, and centralized control mechanisms (Alshamaila et al., 2013).

SMEs face multifaceted challenges that constrain their operational effectiveness and growth potential. Managerial expertise limitations arise from owner-manager structures where proprietors lack essential administrative competencies, leading to reactive rather than proactive decision-making approaches (Adane, 2015). Financial knowledge deficiencies contribute to business failures, with inadequate cash flow management and insufficient revenue generation representing primary concerns (Cant, 2012). Resource constraints encompass limited human resources, financial capabilities, technological access, and expertise, forcing employees to multitask while creating difficulties in obtaining essential human resources and managerial expertise for expansion (Adane, 2015).

2.4 Cloud Computing and SME Performance

Cloud computing presents significant opportunities for SME transformation by enabling organizations to offload entire IT processes while focusing on core operations, reducing substantial infrastructure costs without compromising customer service quality (Bediako-kyeremeh et al., 2019). The technology platform offers potential benefits through enhanced operational capacity and expanded organizational capabilities without requiring additional investments in infrastructure, software, or staff training (Carcary et al., 2014). Appropriate technology utilization enables SMEs to compete more effectively with larger firms, despite traditional barriers associated with high technology adoption costs (Loukis, et al., 2017).

The pay-per-use model addresses SME resource constraints by providing access to sophisticated technologies previously beyond financial reach, enabling better IT resource management responsive to demand fluctuations (Tehrani and Shirazi, 2014). Information and Communication Technology (ICT) adoption can enhance SME efficiency and productivity, with cloud computing offering viable alternatives to traditional on-premises installations while addressing high-cost and high-risk IT project challenges (Khayer et al., 2020). However, SME cloud adoption faces significant barriers including compatibility concerns, contract term complexities, security vulnerabilities, and internet dependency issues, particularly in developing economies with limited reliable internet infrastructure (Widyastuti, 2018)

2.5 SMEs in Ghana: Context and Constraints

Ghana's SME sector constitutes approximately 90% of registered businesses according to Registrar General records, representing a critical demographic for economic expansion as both consumers and employers (Prempeh, 2016). These enterprises operate across diverse sectors including production, processing, trade, import/export, distribution, retail, and service provision, serving as monetary drivers of national revenue while contributing significantly to employment generation and economic output (Thompson et al., 2018).

Financial access limitations represent the most significant barrier, with enterprises relying heavily on retained revenues and informal savings associations that offer limited risk-sharing opportunities due to narrow industry concentration (Prempeh, 2016). Default risk perceptions and insufficient financial facilities restrict formal funding access, while imperfect competition and market imperfections limit loan market accessibility (Adane, 2015). Global competitiveness challenges arise from elevated unit costs, subpar product quality, insufficient standardization, inadequate packaging, and limited market research capabilities, compounded by mac-

roeconomic instability effects including increased commodity prices, insufficient infrastructure, and high taxation rates (Prempeh, 2016).

Technological advancement challenges further constrain SME development, with difficulties in accessing qualified workers and modern equipment creating competitive disadvantages. Many enterprises utilize outdated equipment with limited replacement component availability, while rapid technological evolution requires continuous adaptation to maintain competitive positioning (Ackah, et al., 2011).

2.5 Conceptual Framework

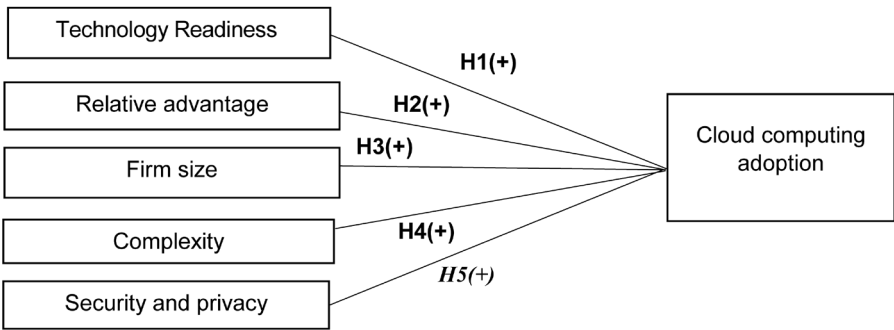


Figure 1. Conceptual Framework and expected signals of hypothesis testing (Source: Author’s construct, 2025).

2.6 Hypothesis

Hypothesis Development

Based on the theoretical framework and literature review, five primary hypotheses emerge regarding cloud computing adoption among SMEs:

Technology Readiness (H1): Organizations with advanced technological capabilities, including appropriate infrastructure and skilled personnel, demonstrate higher propensity for cloud computing adoption. Technology readiness encompasses both structural elements and human resources capable of implementing cloud-based solutions effectively.

Relative Advantage (H2): The degree to which cloud computing is perceived as superior to existing methods influences adoption decisions. Innovations demonstrating clear strategic and operational performance improvements, including increased sales and reduced operating expenses, experience higher adoption rates.

Firm Size (H3): Larger organizations possess greater financial resources and risk tolerance, providing advantages in new technology adoption. Despite smaller firms' adaptability, resource constraints limit their ability to adopt cutting-edge technologies.

Complexity (H4): The perceived difficulty of understanding and implementing cloud computing influences adoption decisions. Complex technologies requiring specialized expertise may face adoption barriers, particularly among organizations with limited technical knowledge or IT specialists.

Security and Privacy (H5): Concerns regarding data security and privacy in shared, multi-user cloud environments influence adoption decisions. Organizations' perceptions of security risks and identity management challenges affect their willingness to migrate to cloud-based solutions.

3. Research Methodology

3.1 Research Design and Philosophical Foundation

This study employs a quantitative research design grounded in a positivist philosophical paradigm to investigate cloud computing adoption among SMEs and its impact on operational performance. The quantitative approach was selected to enable systematic measurement and statistical analysis of relationships between cloud computing adoption factors and SME performance outcomes. As Neuman, (2014) argues, quantitative research utilizes established methods and numerical measures to understand and interpret phenomena, while ensuring validity and generalizability of findings (Marczyk et al., 2010).

The research adopts a deductive approach, moving from established theoretical frameworks in literature to empirical hypothesis testing. This methodology, commonly employed in quantitative studies (Creswell et al., (2007)), enables researchers to use existing literature as a foundation for identifying research questions and developing testable propositions. The deductive approach is particularly appropriate for this investigation as it allows for systematic examination of relationships between cloud computing adoption variables and SME performance indicators identified in the theoretical framework.

3.2 Research Strategy and Approach

A survey-based quantitative strategy was implemented to capture comprehensive data on SME experiences with cloud computing adoption and its operational impacts. This methodological choice facilitates broad generalization of findings across the SME population while enabling rigorous statistical analysis to identify significant relationships between variables (Schoonenboom and Johnson, 2017).

The quantitative approach provides the analytical framework necessary to test proposed hypotheses and contribute empirical evidence to the cloud computing adoption literature.

The survey methodology offers several methodological advantages: (1) standardized data collection across a large SME sample, (2) statistical analysis capabilities to identify patterns and relationships, (3) generalizability of findings to the broader SME population, and (4) quantifiable measures of both cloud computing adoption factors and performance outcomes. The predominantly quantitative nature of the research necessitated deductive methodology, with the researcher drawing on existing literature to develop research questions and inform the development of the data collection instrument.

A five-point Likert scale was employed throughout Sections 3 and 4 to assess participant responses, enabling quantitative measurement of attitudes, perceptions, and experiences. This scaling approach facilitates statistical analysis while providing sufficient response granularity to capture nuanced perspectives on cloud computing adoption and implementation challenges.

3.3 Population and Sampling Framework

3.3.1 Target Population

The target population comprised small and medium-sized enterprises (SMEs) operating in Ghana. According to UNDP reports, approximately 160,000 SMEs were active in Ghana as of 2021 (Arianna, 2021), representing the total accessible population for this study. This population was selected based on the research focus on analyzing how SME adoption of cloud computing affects operational productivity and performance outcomes.

3.3.2 Sampling Technique and Rationale

Convenience sampling was employed as the primary sampling method, specifically targeting owners and managers of SMEs. This non-probability sampling approach was selected for several methodological reasons: (1) the need for respondents with direct knowledge and decision-making authority regarding cloud computing adoption, (2) practical accessibility constraints in reaching SME decision-makers, and (3) the exploratory nature of cloud computing adoption research in the Ghanaian SME context.

While convenience sampling presents limitations regarding statistical generalizability, it provides practical advantages for accessing knowledgeable respondents who can provide meaningful insights into cloud computing adoption experiences and challenges within their organizations.

3.3.3 Sample Size Determination

The Yamane formula was employed to calculate the appropriate sample size for the study population:
population:

$$n = N / (1 + N(e)^2)$$

Where:

- n = required sample size
- N = total population (160,000 SMEs)
- e = margin of error (0.05 or 5%)

$$n = 399$$

The calculation yielded a sample size of 399 SMEs, providing adequate statistical power for the proposed analyses while maintaining a reasonable margin of error of 5%. This sample size enables robust statistical testing of relationships between cloud computing adoption variables and SME performance indicators while supporting generalization to the broader SME population in Ghana (Kyriazos, 2018). The total set of 399 questionnaires were distributed amongst the sample respondents of employees working in various SMEs across Ghana. Out of the 399 questionnaires, 44 were discarded because of the missing information. This represented a response rate of 88.97%.

3.4 Reliability Test

According to Pedhazur and Schmelkin, (2013) and Shrestha, (2021), Cronbach Alpha is one of the well-used methods for assessing reliability of a study questionnaire and is used to assess the reliability of a score. Using IBM SPSS, version 27, reliability tests of the measures were run using Cronbach Alpha. Constructs with a minimum Cronbach Alpha value ($\alpha \geq .70$) passed the initial reliability tests (Pallant and Tennant, 2007).

3.5 Data Collection Procedures

Data collection was conducted through direct administration of the structured questionnaire to identified SME owners, managers, and key employees with knowledge of their organization's technology adoption decisions and operational performance. The survey was designed to capture both information about cloud computing adoption status and perceptual data regarding implementation experiences, benefits realized, and challenges encountered.

The multi-section questionnaire design ensures comprehensive coverage of the research variables while maintaining respondent engagement through logical flow and varied question formats. The use of Likert scales in performance and challenge assessment sections enables quantitative analysis while allowing respondents to express varying degrees of agreement or experience intensity.

This methodological framework provides the foundation for rigorous empirical investigation of cloud computing adoption patterns and performance impacts among Ghanaian SMEs, contributing valuable evidence to the growing body of literature on technology adoption in developing economy contexts.

4. Findings and Discussion

This study collected data from 355 respondents across various SMEs in Ghana, providing comprehensive insights into cloud computing adoption patterns and their operational impacts. The sample comprised employees (64%, n=226), supervisors (18%, n=65), and managers (18%, n=64), ensuring representation across organizational hierarchies with decision-making authority regarding technology adoption.

Table 1 Demographic Characteristics

Characteristics	Category	Frequency	Percentage
Gender	Male	269	76%
	Female	86	24%
Education	WASSCE/BECE	18	5%
	Diploma	40	11%
	Bachelor's	158	45%
	Master's	117	117
	PhD	22	6%
Total		355	100%

(Source: Fieldwork, 2025)

4.1 Cloud Adoption

Cloud services were employed by a considerable number (173) of small and medium-sized organizations (SMEs) that were surveyed. This totaled 49% of the responses. Furthermore, 81 SMEs representing 23% of respondents stated that their organizations were expected to adopt and use cloud services in the next six months. On the other hand, 92 respondents, representing 26% of all respondents, stated that they had no intention of adopting and utilizing any cloud services soon. The results of this study indicate that, majority of SMEs employ the use of some form of cloud technology. This implies that cloud computing adoption among SMEs in Ghana is progressing steadily despite the existence of structural and perceptual barriers. This rate of adoption mirrors previous findings of Mazumdar, (2018). who emphasized the democratizing potential of cloud computing for small businesses in low-resource settings.

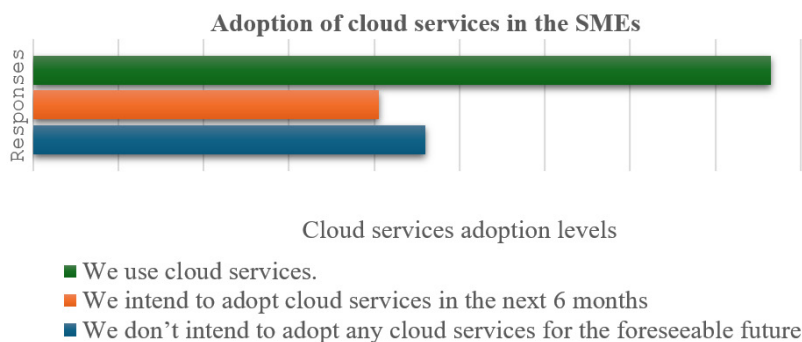


Figure 2. Depiction of the utilization of cloud services in the SMEs.

4.2 Impact on SMEs

4.2.1 Impact on SMEs Performance and Operational Efficiency

The analysis of cloud computing's impact on business performance focused on two key dimensions: improved market reach and enhanced data management capabilities. Statistical analysis revealed significant positive impacts in both areas, with mean scores of 2.92 (SD=1.248) for improved market reach and 2.93 (SD=1.258) for ease in data management and administration.

One-way ANOVA results demonstrated statistically significant differences in performance outcomes based on cloud adoption motivations. For improved market reach, $F(25,330) = 8.39$, $p < 0.001$, and for data management ease, $F(25,330) = 6.76$, $p < 0.001$, both indicating significant positive relationships between cloud adoption

and performance outcomes. Further ANOVA analysis identified significant factors determining cloud computing adoption decisions among SMEs. Key factors included ease of workload management ($F=6.787, p<0.001$), agility and innovation capabilities ($F=7.987, p<0.001$), staffing considerations ($F=9.083, p<0.001$), cloud expertise availability ($F=5.783, p<0.001$), enhanced productivity ($F=8.975, p<0.001$), data accessibility ($F=6.754, p<0.001$), and affordable storage options ($F=6.216, p<0.001$).

The results from the ANOVA tests for the current study illustrates that market reach and data management, which are both statistically significant, are outcomes of cloud adoption. This also indicates that cloud adoption is not merely a strategic aspiration but a tangible operational asset for SMEs in Ghana. The results is also in line with Arvanitis et al., (2017) who asserts that, cloud adoption by SMEs enables them to compete with larger firms. Additionally, the statistical significance of the operational efficiency variables demonstrates the use of cloud services can help SMEs overcome traditional barriers such as storage and data accessibility. This is in line with Khayer et al., (2020a).

Table 2. Impact on SMEs Performance

Performance Variables	N	Mean	Std. Deviation	F-Value	Significance
Improved Market Reach	355	2.92	1.248	8.39	0.001*
Data Management Ease	355	2.93	1.258	6.76	0.001*

(Source: Fieldwork, 2025)

4.2.2 Hypothesis Testing Results

A one-sample test was conducted to test the hypothesis that technological readiness will positively influence cloud-computing adoption. The results showed that respondents reported higher technology readiness for cloud computing adoption ($M=3.18$, $SD=0.91$) than the population, with a t-value of 66.16 and $p < 0.05$. This indicates that technological readiness has a positive influence on cloud computing adoption and therefore the hypothesis is accepted. The high level of technology readiness exhibited by SMEs in this study can potentially be attributed to their utilization of cloud computing in their operational processes. Recent study by Low, et al., (2011) supports the hypothesis that technology readiness will positively influence cloud computing adoption. However, a study by Sithole and Ruhode (2021), was found inconsistent with the hypothesis.

In the case of relative advantage, the respondents reported a mean of 2.92 ($SD=1.25$) in analyzing the relative advantage. This mean was then compared to the entire population, but no significant difference was found. The t-value was 44.01, and the p-value was less than 0.05, Therefore, the hypothesis is accepted. This result indicates that relative advantage has a positive impact on cloud computing adoption among SMEs in Ghana. In that, the concept of relative advantage encompasses the various benefits and opportunities offered by cloud computing, such as cost reduction, enhanced competitiveness, and scalability. Thus, has a strong significance in influencing cloud computing adoption among SMEs as reported by Tan et al., (2010).

For firm size, the respondents reported an average size of 2.15 (with a standard deviation of 0.781). No significant difference was found when comparing this average to that of the entire population. The t-value was 51.94, with a p-value of less than 0.05, which indicates that firm size positively affects SMEs adoption of cloud computing, hence the hypothesis is accepted. A possible reason for this was that the broader the geographical reach of small and medium-sized enterprises (SMEs), the higher the probability of their adoption of cloud computing. This is due to the perception that cloud computing offers opportunities to expand client base, consolidate IT infrastructure, and enhance cooperation, among other advantages which is in line with findings from Sithole and Ruhode, (2021).

Table.3 Hypothesis Results

Hypothesis	Mean	SD	t-value	p-value	Result
H1: Technology Readiness	3.18	0.91	66.16	<0.001	Accepted
H2: Relative Advantage	2.92	1.25	44.01	<0.001	Accepted
H3: Firm Size	2.15	0.781	51.94	<0.001	Accepted
H4: Complexity	2.69	1.21	41.99	<0.001	Accepted
H5: Security and Privacy	2.68	1.12	44.83	<0.001	Accepted

(Source: Fieldwork, 2025)

A one-sample test to evaluate the complexity involved in using cloud computing, comparing it to the population mean. The respondents reported a mean of 2.69 (SD=1.21), which when compared to the entire population indicated no significant difference. With a t-value of 41.99 and a p-value of less than 0.05, it appears that complexity positively affects the adoption of cloud computing, therefore the hypothesis is accepted. A possible explanation for the complexity involved in cloud adoption among some SMEs can be attributed to the perception that cloud computing is characterized by user-friendliness, as it streamlines the management of IT systems and facilitates the development and distribution of applications. Nonetheless, a findings from Oliveira and Martins (2010),were found to not support this hypothesis. A possible reason for this would have to do with the small sample size used in their study.

Lastly, a one-sample test to assess the security and privacy concerns associated with using cloud computing and compared it with the population mean. The respondents reported a mean score of 2.68 with a standard deviation of 1.12, which when compared to the entire population indicated no significant difference. This implies that security and privacy have a positive impact on the adoption of cloud computing. The t-value was 44.83, and the p-value was less than 0.05. Therefore, the hypothesis is accepted. A possible reason for this was the increased securi-

ty and privacy awareness among SMEs owners and managers over the years and cloud computing platforms' ability and track record of improved and beefed-up security of their services as espoused by Khan and Al-yasiri, (2015).

5. Conclusion and Recommendations

This study examined cloud computing adoption determinants and performance impacts among Ghanaian SMEs using a DOI framework. The findings reveal that internal technological capabilities, perceived strategic benefits, and organizational characteristics significantly influence cloud adoption. Technology readiness and relative advantage emerged as key drivers, indicating that SMEs adopt cloud solutions when they perceive alignment with operational needs and possess adequate internal infrastructure. Firm size proved significant, with larger SMEs better positioned to absorb transition costs and leverage strategic benefits due to their complex operations and superior financial capacity.

While complexity negatively influenced adoption, it remained statistically significant, highlighting persistent challenges in simplifying cloud integration for resource-constrained firms. Unexpectedly, security and privacy concerns showed no significant impact on adoption decisions, suggesting either increased vendor trust or prioritization of operational advantages over security apprehensions. The study confirms positive performance implications, with adopting SMEs reporting tangible improvements in market reach and data management efficiency, establishing cloud computing as a viable pathway for competitiveness and scalability in Ghana's challenging business environment.

Managerial Implications: SME managers and entrepreneurs must approach cloud adoption as organizational transformation rather than an isolated technological choice. This requires deliberate investment in digital strategy development and capacity building, aligning cloud technologies with long-term strategic goals including market expansion, efficiency improvements, and data-driven decision-making. Addressing complexity barriers necessitates technical training and improved vendor communication that translates technological propositions into understandable business outcomes. The persistence of complexity as a deterrent demand simplified onboarding processes, user-friendly interfaces, and tiered service options matching varying digital maturity levels.

Policy Recommendations: Policymakers should create enabling environments through infrastructural investments in broadband access, cloud adoption incentives, and regulatory clarity on data protection. Public-private partnerships and

SME support programs offering training, subsidized access, and cooperative purchasing arrangements can facilitate broader uptake and digital transformation across Ghana's SME sector.

References

Ackah, A.J., Vuvor, S. and Lovstal (2011) 'The Challenges faced by Small & Medium Enterprises (SMEs) in Obtaining Credit in Ghana.'

Adane, M. (2015) 'A Framework for Cloud Computing Adoption in Small and Medium-sized Enterprises : A Case of the Accra-Tema Metropolis in Ghana By'.

Arianna, G. (2021) Understanding MSMEs and Entrepreneurs' Appetite for Crowdfunding Solutions in Ghana. Available at: <https://www.uncdf.org/article/6509/understanding-msmes-and-entrepreneurs-appetite-for-crowdfunding-solutions-in-ghana> (Accessed: 29 December 2022).

Bediako-kyeremeh, B., Duorinaa, E. and Agyemang, S. (2019) 'Stu international journal of technology (stuijt)', 1(7).

Berisha, G. and Pula, J.S. (2017) 'Exploring suitability of cloud computing for small and medium-sized enterprises in India', *Journal of Small Business and Enterprise Development*, 24(4), pp. 814–832. Available at: <https://doi.org/10.1108/JSBED-01-2017-0002>.

Berriman, G.B. et al. (2013) 'The application of cloud computing to scientific workflows: a study of cost and performance', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 371(1983), p. 20120066.

Busch, P. et al. (2014) 'A study of government cloud adoption: The Australian context', *Proceedings of the 25th Australasian Conference on Information Systems, ACIS 2014* [Preprint].

Cant, M. (2012) 'Challenges Faced By SME ' s In South Africa : Are Marketing Skills Needed ?', 11(10), pp. 1107–1116.

Carcary, M., Doherty, E. and Conway, G. (2014) 'The Adoption of Cloud Computing by Irish SMEs – an Exploratory Study', 17(1), pp. 3–14.

Corvello, V. et al. (2022) 'The digital transformation of entrepreneurial work', *International Journal of Entrepreneurial Behaviour and Research*, 28(5), pp. 1167–1183.

Available at: <https://doi.org/10.1108/IJEBR-01-2021-0067>.

Crewell, J.W., Piano, C. and Vicki, L. (2007) 'Designing and conduction mixed methods research'.

Garrison, G., Kim, S. and Wakefield, R.L. (2012) 'Success factors for deploying cloud computing', *Communications of the ACM*, 55(9), pp. 62–68.

Gkikas, D. (2014) 'The Impact of Cloud Computing on Entrepreneurship and Start-ups: Case of Greece', *Cloud Computing* [Preprint].

Govender, J. (2016) 'Adoption of Cloud Computing By the South African Public Sector'.

Gupta, P., Seetharaman, A. and Raj, J.R. (2013) 'The usage and adoption of cloud computing by small and medium businesses', *International Journal of Information Management*, 33(5), pp. 861–874. Available at: <https://doi.org/10.1016/j.ijinfo-mgt.2013.07.001>.

Jamsa, K. (2013) 'Cloud Computing SaaS, PaaS, IaaS, Virtualization, Business Models, Mobile, Security, and More'. Jones & Bartlett Learning, United States of America.

Kevin Namiro Kuteesa, Chidiogo Uzoamaka Akpuokwe and Chioma Ann Udeh (2024) 'Navigating the digital transformation journey: strategies for startup growth and innovation in the digital era', *International Journal of Scholarly Research in Multidisciplinary Studies*, 4(2), pp. 038–053. Available at: <https://doi.org/10.56781/ijss-rms.2024.4.2.0031>.

Khayer, A. et al. (2020) 'Cloud computing adoption and its impact on SMEs' performance for cloud supported operations: A dual-stage analytical approach', *Technology in Society*, 60(September 2019), p. 101225. Available at: <https://doi.org/10.1016/j.techsoc.2019.101225>.

Kyriazos, T.A. (2018) 'Applied Psychometrics: Sample Size and Sample Power Considerations in Factor Analysis (EFA, CFA) and SEM in General', *Psychology*, 09(08), pp. 2207–2230. Available at: <https://doi.org/10.4236/psych.2018.98126>.

Loukis, E., Arvanitis, S. and Kyriakou, N. (2017) 'An empirical investigation of the effects of firm characteristics on the propensity to adopt cloud computing', *Information Systems and e-Business Management*, 15, pp. 963–988.

Ackah, A.J., Vuvor, S. and Lovstal (2011) 'The Challenges faced by Small & Medium Enterprises (SMEs) in Obtaining Credit in Ghana.'

Adane, M. (2015) 'A Framework for Cloud Computing Adoption in Small and Medium-sized Enterprises : A Case of the Accra-Tema Metropolis in Ghana By'.

Arianna, G. (2021) Understanding MSMEs and Entrepreneurs' Appetite for Crowdfunding Solutions in Ghana. Available at: <https://www.uncdf.org/article/6509/understanding-msmes-and-entrepreneurs-appetite-for-crowdfunding-solutions-in-ghana> (Accessed: 29 December 2022).

Bediako-kyeremeh, B., Duorinaa, E. and Agyemang, S. (2019) 'Stu international journal of technology (stuijt)', 1(7).

Berisha, G. and Pula, J.S. (2017) 'Exploring suitability of cloud computing for small and medium-sized enterprises in India', *Journal of Small Business and Enterprise Development*, 24(4), pp. 814–832. Available at: <https://doi.org/10.1108/JSBED-01-2017-0002>.

Berriman, G.B. et al. (2013) 'The application of cloud computing to scientific workflows: a study of cost and performance', *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 371(1983), p. 20120066.

Busch, P. et al. (2014) 'A study of government cloud adoption: The Australian context', *Proceedings of the 25th Australasian Conference on Information Systems, ACIS 2014* [Preprint].

Cant, M. (2012) 'Challenges Faced By SME ' s In South Africa : Are Marketing Skills Needed ?', 11(10), pp. 1107–1116.

Carcary, M., Doherty, E. and Conway, G. (2014) 'The Adoption of Cloud Computing by Irish SMEs – an Exploratory Study', 17(1), pp. 3–14.

Corvello, V. et al. (2022) 'The digital transformation of entrepreneurial work', *International Journal of Entrepreneurial Behaviour and Research*, 28(5), pp. 1167–1183. Available at: <https://doi.org/10.1108/IJEBr-01-2021-0067>.

Crewell, J.W., Piano, C. and Vicki, L. (2007) 'Designing and conduction mised methods research'.

Garrison, G., Kim, S. and Wakefield, R.L. (2012) 'Success factors for deploying cloud computing', *Communications of the ACM*, 55(9), pp. 62–68.

Gkikas, D. (2014) 'The Impact of Cloud Computing on Entrepreneurship and Start-ups : Case of Greece', *Cloud Computing* [Preprint].

Govender, J. (2016) 'Adoption of Cloud Computing By the South African Public Sector'.

Gupta, P., Seetharaman, A. and Raj, J.R. (2013) 'The usage and adoption of cloud computing by small and medium businesses', *International Journal of Information Management*, 33(5), pp. 861–874. Available at: <https://doi.org/10.1016/j.ijinfomgt.2013.07.001>.

Jamsa, K. (2013) 'Cloud Computing SaaS, PaaS, IaaS, Virtualization, Business Models, Mobile, Security, and More'. Jones & Bartlett Learning, United States of America.

Kevin Namiro Kuteesa, Chidiogo Uzoamaka Akpuokwe and Chioma Ann Udeh (2024) 'Navigating the digital transformation journey: strategies for startup growth and innovation in the digital era', *International Journal of Scholarly Research in Multidisciplinary Studies*, 4(2), pp. 038–053. Available at: <https://doi.org/10.56781/ijss-rms.2024.4.2.0031>.

Khayer, A. et al. (2020) 'Cloud computing adoption and its impact on SMEs' performance for cloud supported operations: A dual-stage analytical approach', *Technology in Society*, 60(September 2019), p. 101225. Available at: <https://doi.org/10.1016/j.techsoc.2019.101225>.

Kyriazos, T.A. (2018) 'Applied Psychometrics: Sample Size and Sample Power Considerations in Factor Analysis (EFA, CFA) and SEM in General', *Psychology*, 09(08), pp. 2207–2230. Available at: <https://doi.org/10.4236/psych.2018.98126>.

Loukis, E., Arvanitis, S. and Kyriakou, N. (2017) 'An empirical investigation of the effects of firm characteristics on the propensity to adopt cloud computing', *Information Systems and e-Business Management*, 15, pp. 963–988.

Low, C., Chen, Y. and Wu, M. (2011) 'Understanding the determinants of cloud computing adoption', *Industrial Management and Data Systems*, 111(7), pp. 1006–1023. Available at: <https://doi.org/10.1108/02635571111161262>.

Magoulès, F., Pan, J. and Teng, F. (2012) *Cloud computing: Data-intensive computing and scheduling*. CRC press.

Marczyk, G.R., DeMatteo, D. and Festinger, D. (2010) *Essentials of research design and methodology*. John Wiley & Sons.

Marston, S. et al. (2011) 'Cloud computing - The business perspective', *Decision Support Systems*, 51(1), pp. 176–189. Available at: <https://doi.org/10.1016/j.dss.2010.12.006>.

Mazumdar, A. (2018) 'Adoption of Cloud Computing in the SMEs: An Exploration of the Issues and Challenges for Adoption of Cloud Computing by SMEs in Bangladesh in the Context of "Digital Bangladesh"', PQDT - Global, p. 371. Available at: <https://search.proquest.com/docview/2384466918?accountid=13460%0Ahttps://zp2yn2et6f.search.serialssolutions.com/directLink?&atitle=Adoption+of+-Cloud+Computing+in+the+SMEs%3A+An+Exploration+of+the+Issues+and+Challenges+for+Adoption+of+Cloud+Computing+by+SME>.

Neuman, D. (2014) 'Qualitative research in educational communications and technology: A brief introduction to principles and procedures', *Journal of Computing in Higher Education*, 26, pp. 69–86.

Oliveira, T. and Martins, M.F. (2010) 'Information technology adoption models at Firm Level: Review of literature', 4th European Conference on Information Management and Evaluation, ECIME 2010, 14(1), pp. 312–322.

Pallant, J.F. and Tennant, A. (2007) 'An introduction to the Rasch measurement model: an example using the Hospital Anxiety and Depression Scale (HADS)', *British journal of clinical psychology*, 46(1), pp. 1–18.

Papazoglou, M.P. (2003) 'Service-oriented computing: Concepts, characteristics and directions', in *Proceedings of the Fourth International Conference on Web Information Systems Engineering*, 2003. WISE 2003. IEEE, pp. 3–12.

Pedhazur, E.J. and Schmelkin, L.P. (2013) *Measurement, design, and analysis: An integrated approach*. psychology press.

Prempeh, K.B. (2016) 'PROBLEMS OF FINANCING SMEs IN GHANA: A CASE STUDY OF THE Abstract : -', 1(1), pp. 28–47.

Schoonenboom, J. and Johnson, R.B. (2017) 'How to construct a mixed methods research design', *Kolner Zeitschrift fur Soziologie und Sozialpsychologie*, 69(Suppl 2), p. 107.

Shrestha, N. (2021) 'Factor Analysis as a Tool for Survey Analysis', *American Journal of Applied Mathematics and Statistics*, 9(1), pp. 4–11. Available at: <https://doi.org/10.12691/ajams-9-1-2>.

Sithole, S.S. and Ruhode, E. (2021) 'Dedication Cloud computing adoption: challenges and opportunities for small, medium and micro enterprises in South Africa', *Proceedings of the 1st Virtual Conference on Implications of Information and Digital Technologies for Development*, pp. 282–301.

Tan, K.S. et al. (2010) 'Internet-based ICT adoption among SMEs: Demographic versus benefits, barriers, and adoption intention', *Journal of Enterprise Information Management*, 23(1), pp. 27–55. Available at: <https://doi.org/10.1108/17410391011008897>.

Tehrani, S.R. and Shirazi, F. (2014) 'Factors Influencing the Adoption of Cloud Computing by Small and Medium Size Enterprises (SMEs)', pp. 631–642.

Thompson, G., Frederick, A. and Chima, M. (2018) 'Factors influencing the growth of SMEs: The case of Ghana', pp. 549–563. Available at: <https://doi.org/10.1002/tie.21945>.

Widyastuti, D. (2018) 'Benefits And Challenges Of Cloud Computing Technology Adoption In Small And Medium Enterprises (SMEs)', 41, pp. 241–246.

Art Beyond Barriers: How Universal Design For Learning Shapes Education For Students With Learning Disabilities In Visual Arts Classrooms

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ABSTRACT:

Universal Design for Learning (UDL) is not simply an accommodation strategy for students with disabilities, but it is also a universal approach to quality teaching that benefits all learners when applied intentionally and contextually. Nowhere is this need more pressing than in Ghana's mainstream Senior High Schools (SHS), where students with learning disabilities (LDs) often face a silent crisis of exclusion caused by inadequate teacher preparedness, stigmatising attitudes, and a lack of differentiated instructional tools. This study examined Visual Arts students with learning disabilities' perceived value of UDL in teaching and learning in a co-educational public mainstream SHS in the Ashanti region. A convergent parallel research design was employed to solicit data from a convenience and purposive sample of 100 SHS2 visual arts students through a questionnaire and observation. The findings revealed three categories of students: normative students (56%), students with LDs (31%), and SEND (13%). Students perceived and valued the UDL principles of providing multiple means of representation (mean=4.29 or 85.8%), engagement (mean=4.23 or 86.4%) and action and expression (mean=4.28 or 85.6%). As such there is a significantly positive and strong relationship between UDL principles and students' multiple forms of representation ($r(98) = 0.73$, " $p < .001$ "), engagement ($r(98) = 0.75$, " $p < .001$ ") and action and expression ($r(98) = 0.71$, " $p < .001$ "). This implies UDL principles positively and significantly predict students with learning disabilities' learning outcomes, $R = .96$, $F(1, 98) = 1054$, " $p < .001$ with a large effect size ($R = .971$) as it fosters academic performance and participation.

KEYWORDS: Universal Design For Learning, Learning Disabilities, Visual Arts Students, Mainstream Senior High School

1. Introduction

In a rapidly diversifying global education landscape, the pursuit of inclusive education has emerged as both a moral and pedagogical imperative. Central to this movement is Universal Design for Learning (UDL), a transformative educational framework that challenges the traditional “one-size-fits-all” model of teaching. UDL promotes flexible curriculum design that accommodates the full spectrum of learner variability and ensures equitable access, participation, and progress for all students, especially those with learning disabilities (LDs) (King-Sears et al., 2023). Through its three core principles: multiple means of engagement, representation, and expression, UDL provides a scaffolded structure that fosters meaningful learning experiences (Syre-Hager, 2022; Niad et al., 2021).

Emerging studies within Ghana highlight the promise of UDL in reimagining inclusive education. Pioneering work by Adom et al. (2023) in visual arts education has demonstrated how UDL principles can democratize access to content and foster active learning. Additionally, Niad et al. (2021) provide technical guidance for educators to implement UDL strategies effectively, particularly for learners with difficulties. Likewise, Nantwi et al. (2023) demonstrate that art teachers who applied UDL strategies improved classroom inclusivity. These findings align with international evidence that confirms the adaptability of UDL across cultural and educational settings (Almumen, 2020). Regardless of the positive examples of UDL, this framework remains isolated and has not translated into widespread practice within the Visual Arts domain, where creativity, diversity, and individualised expression are core but frequently constrained by rigid instructional models (Adom, 2022). Nowhere is UDL more pressing than in mainstream SHS visual arts classrooms, where students with LDs often face exclusion caused by inadequate teacher preparedness, stigmatising attitudes, and a lack of differentiated instructional tools (Opoku, 2022).

In line with this analogy, the study employed a convergent parallel research design to ascertain how UDL shapes the educational prospects of students with LDs in visual arts classrooms. Data was gathered through a questionnaire, observation, and focus group discussion, which were analysed both quantitatively and qualitatively. Although the Global Initiative for Inclusive ICT (2020) reported UDL implementation in SHSs in the Upper West, Upper East, North East, and Northern regions, these efforts were confined to students in special schools, not in mainstream SHS settings or visual arts students with LDs. Again, Adom (2022) reflects on his UDL practice as an SHS visual art teacher but is silent on students with LDs. This study, therefore, aimed at adopting UDL principles to shape the educational prospects of students with LDs in visual arts classrooms by means of practical strategies such

as differentiated instruction, flexible assessment methods, and adapting learning environments towards addressing the educational needs of all learners.

2. Literature Review

2.1 UDL Framework and Its Core Components

Universal Design for Learning (UDL) is an educational framework grounded in cognitive neuroscience that aims to make learning accessible and effective for all learners, particularly those with disabilities. Developed by CAST, UDL emphasises flexible curriculum design to accommodate learner variability (CAST, 2024). The framework revolves around three core principles: Multiple Means of Engagement, Representation, and Action and Expression, each addressing the why, what, and how of learning (Rao et al., 2023). Recent studies affirm UDL's growing relevance in inclusive education. Levey (2023) explains that UDL promotes educational equity through anticipation of diverse learning needs. This is especially relevant in visual arts classrooms, where traditional methods can hinder creative expression among students with learning disabilities. UDL enables such classrooms to evolve into inclusive environments that support different ways of engaging, perceiving, and expressing knowledge.

2.2 Multiple Means of Representation

This principle focuses on presenting information in various formats to aid perception and comprehension. Students with LDs often struggle with decoding language, interpreting symbols, or understanding abstract concepts, which are key in visual arts education (CAST, 2024). Nave (2021) notes that integrating visual diagrams, videos, and interactive simulations supports understanding of complex ideas. Hence, the use of Videos, PowerPoint presentations, and Printouts can be used to make lessons more tangible and reduce cognitive load. Almeqdad et al. (2023) affirm that UDL's representation strategies enhance academic performance, especially for students with diverse learning needs. In visual arts classrooms, layered scaffolds, step-by-step visuals, or symbol-supported instructions can increase content accessibility.

2.3 Multiple Means of Engagement

This principle addresses how learners get involved and stay motivated. For students with LDs, sustaining attention in traditional classrooms is often challenging (CAST, 2024). UDL suggests providing choice, autonomy, and emotional support to maintain engagement. Saunders and Wong (2023) and Adler and Kletenik (2025)

argue that allowing choice in content, tools, and assessment boosts intrinsic motivation. In visual arts, this could mean choosing materials or themes based on interest and increasing emotional investment. Moleko (2021) adds that adaptive strategies like gamification and peer collaboration benefit students with attention difficulties. UDL also builds community and encourages self-regulation, which tends to reduce anxiety and frustration (Owiny & Hartmann, 2020). These strategies support both academic achievement and emotional well-being.

2.4 Multiple Means of Action and Expression

This principle concerns how learners demonstrate their knowledge. Students with LDs may have difficulties with motor coordination, organisation, or expressive language, which can impact art assessments (CAST, 2024). Capp (2017) recommends the provision of varied options such as oral presentations, portfolios, or exhibitions. In the visual arts, this flexibility allows students to showcase their strengths and minimise their limitations. Sewell et al. (2022) have framed UDL as an inclusive practice aligned with educational psychology, which enables student agency. Hollingshead (2018) adds that experiential and project-based learning fosters metacognition and independence. These approaches benefit all learners and confirm UDL's broader effectiveness (Rao et al., 2023).

2.5 Learning Disabilities

Learning disabilities (LDs) are neuro-developmental disorders that interfere with acquiring, organising, retaining, or using verbal or non-verbal information. They manifest in difficulties with listening, speaking, reading, writing, spelling, or performing mathematical tasks (U.S. DoE, 2025). This definition reflects the broad and heterogeneous nature of LDs, which can impact visual arts students' academic and creative performance.

2.6 Identification Methods and Challenges

Maki and Adams (2019) explain that LD identification remains inconsistent due to varied models, limited educator training, and the absence of standardised criteria. Schools adopt cognitive discrepancy or response-to-intervention (RTI) approaches. This inconsistency can delay or prevent accurate identification, especially for highly creative students who mask academic difficulties. Famolu (2020) stresses the role of an interdisciplinary collaboration involving educators, counsellors, and specialists. For arts students, behavioural observations, portfolio assessments, and performance tasks should supplement standardised tests. The Government of New Brunswick (2003) recommends combining observations, functional assessments, and teacher reports to better support high school learners with LDs.

This approach aligns with the UDL value of promoting instruction tailored to individual strengths.

2.7 International and Inclusive Perspectives

Globally, identification frameworks are shifting toward more inclusive, culturally responsive systems. Lien (2025) proposes a systems-theoretical approach that decolonises Special Educational Needs and Disabilities (SEND), urging recognition of how social structures influence diagnosis and access. Alghrani et al. (2024) highlight a crisis in SEND assessments, advocating for early intervention, family involvement, and well-trained assessors aligned with UDL. The NC DPI Exceptional Children Division (2021) stresses documentation and individualised plans to guide support. These enable educators to apply UDL strategies like varied expression and targeted feedback. The Middlesbrough Council (2021) emphasises inclusive policies backed by professional development. However, without systemic commitment, even strong UDL designs may fall short in supporting students with LDs in the arts.

2.8 Learning Disabilities Identification Based on Academic Benchmark

In Ghana, students complete junior high school (JHS) by age 14 and transition into SHS between ages 15-18 (MoE, 2018). Placement is determined by the Computerised Selection and Placement System (CSSPS), which works with BECE results, school choices, and a deferred acceptance algorithm (Babah et al., 2020). Aggregates 6-15 enter Category A, 10-25 go to Category B, while 10-30 go to Category C schools (Opoku-Asare et al., 2015). Due to systemic perceptions shaped by identity and system justification theories (Baidoo-Anu et al., 2022), low-performing students are often assigned to pursue visual arts, regardless of interest (Kankam et al., 2023), leading to discrimination, especially in core subjects (Opoku-Asare et al., 2015). Interestingly, Zwane and Malale (2018) have linked BECE underperformance to learning disabilities. Guided by IDEA 2004 (U.S. DoE, 2025), NC DPI (2021), Government of New Brunswick (2003), and category benchmarks (Kankam et al., 2023), students who scored 10-25 were normative, 26-30 were labelled as learning disabled, and those placed in visual arts despite falling below all categories were identified as having SEND (Lien, 2025). Teaching these students is demanding and time-intensive.

3. Research Methodology

Guided by the pragmatism paradigm, the study employed a mixed-methods approach with a convergent parallel design to gather data from Form 2 visual arts students in one public SHS. Convenience and purposive sampling techniques were used to select participants (Terrell, 2022). Due to the relatively small accessible population (n=114) and the attempt to include all students, the sample size (n=100) was based on a near-census approach (Nanjundeswaraswamy & Divakar, 2021). With ethical clearance from EIST-KNUST (EIST/S/3) and Ghana Education Service (T.J14/90/22), the study was conducted in Juaben SHS in the Ashanti region, between 17th February and 28th May 2025 (15 weeks). A pilot study was conducted with 85 Form 3 visual arts students between the 13th and 31st of January 2025. Necessary modifications to the research instrument were made before the main study began with Form 2 students. Data was collected through a questionnaire and observation. CAST's (2024) UDL 36-item scale, with nine subscales across three broad themes, was used for quantitative data collection. It was measured on a 5-point Likert scale (1 = strongly disagree, 3 = neutral, 5 = strongly agree). Jamovi (2.5.6) was used for analysis and yielded a Cronbach's alpha ($\alpha = 0.805$). Qualitative data analysis followed Braun and Clarke's (2006) thematic analysis. Both data types were triangulated and analysed according to the study's objectives. Participants' consent was sought, and they were assured of anonymity, confidentiality, data security, and privacy.

4. Findings and Discussions

4.1 Study Participants

4.1.1 Age and Gender

Table 1 indicates the age and gender of the sampled visual arts students, with the majority (66%) being male, while age-wise, 89% were between 15 and 18 years old. Details on age and gender are presented in **Table 1**.

Table 1: Age and Gender of Participants

Class/Form	Gender	Age	Frequency	% of Total	Total
SHS2	Female	Below 15	1	1.0 %	34 (34%)
		15-18	30	30.0 %	
		19-22	3	3.0 %	
	Male	Below 15	4	4.0 %	66 (66%)
		15-18	59	59.0 %	
		19-22	3	3.0 %	

4.1.2 BECE Aggregate Scores of Students

The Ministry of Education (MoE) and Ghana Education Service (GES) are saddled with social identity and system justification theories, and as such, students with lower scores are often assigned to the visual arts programme irrespective of their interests or strengths (Kankam et al., 2023). On that premise, the study sought to ascertain the BECE aggregate scores of the sampled visual arts students. Figure 1 indicates aggregate 15-18 (8%) as upper-performance students, and aggregate 19-25 (48%) as lower-to-mid performance students. This implies that the sampled students’ performance was skewed towards the lower end of category B schools’ grade criteria. However, aggregates 26-40 (44%) were deemed as ‘underperforming or academically weak’ students and were also recorded (Kankam et al., 2023). Details of the aggregate distributions are illustrated in Fig. 1.

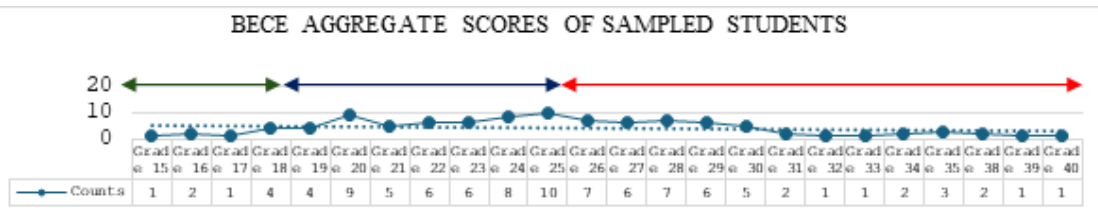


Fig. 1: BECE Aggregates of Visual Arts Students
(Source: Field Data, 2025)

4.1.3 Categorisation of Students Based on BECE Aggregates

Based on IDEA 2004 (US Department of Education, 2025), Specific Learning Disability Fact Sheet #4 (NC DPI Exceptional Children Division, 2021), Learning Disability Identification Manual (Government of New Brunswick, 2003), and the aggregate criteria for category B SHSs (Kankam et al., 2023), the sampled visual arts students were categorized into three groups with normative students (56%) being dominant. Table 2 presents the detailed distribution of the groupings.

Table 2: Categorisation of Students Based on BECE Aggregates

LD Category	BECE Aggregates	Frequency	% of Total
Normative Students	Aggregate 25 and below	56	56.0 %
Students with LD	Aggregate 26-30	31	31.0 %
Students with SEND	Aggregate 31 and above	13	13.0 %
Total		100	100.0%

4.1.4 Identification of Students' Learning Disabilities

Guided by the Learning Disability Identification Manual (Government of New Brunswick, 2003), the sampled students manifested varied forms of learning disabilities spread across the three categorised groups. Table 3 indicates that the majority (63%) manifested more than one form of learning disability, with the normative students being the worst casualty (56%). The details of the data distribution are shown in Table 3.

Table 3: Students’ Manifestation of Learning Disabilities

Specific Learning Disability	Normative Student	Student with LD	Student with SEND	Total
1 Form of Learning Disability	20	11	6	37
2 Forms of Learning Disabilities	22	10	4	36
Multiple Forms of Learning Disabilities	14	10	3	100
Total	56	31	13	100

(Source: Field Data, 2025)

4.2 Students’ Perception of UDL Usage in Teaching and Learning

Owing to the manifestation of learning disabilities among the sampled visual arts students, UDL principles were adapted as a teaching and learning methodology. The CAST (2024) UDL 36-item scale was used to elicit the students’ responses on the perceived value of UDL in teaching and learning. Their responses were summarised using statistical metrics: mean, median, and standard deviation. The statistical mean of the scale is 2.5 for Likert scale 1-2-3-4-5 (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree). Results above 2.5 were deemed favourable and positive toward UDL usage under the three core principles of multiple means of representation, engagement, and action and expression.

4.2.1 Teaching and Learning Sessions Using UDL Principles

During the study period, various aspects of UDL principles were applied to enhance the teaching and learning of the sampled visual arts students with LDs. Under multiple means of representation, Figures 2-4 illustrate how accessible materials such as PowerPoint presentations, videos, and printed handouts were used to support learning from varied perspectives.



Fig. 2: PowerPoint Presentation Material



Fig. 3: Video Presentation



Fig. 3: Printable



Fig. 4: Sawmill field trip



Fig. 5: Project-based learning



Fig. 6: Experiential learning

On multiple means of engagement, field trips to a nearby wood sawmill (at Juaben), project-based learning (both individual and group work), experiential learning and personalised learning approaches were employed to optimise the learning experience and spark joy and playfulness in the learning process. Figures 4-7 illustrate how the students were engaged in varied approaches under the guiding principle of UDL.

(Source: Field Data, 2025 – Multiple Means of Engagement)



Fig. 7: Oral presentation exhibition



Fig. 8: Group Exhibition

4.2.2 Perception of UDL as a Teaching Methodology

UDL promotes a proactive and flexible teaching methodology that accommodates variability and ensures equitable access, participation, and progress for all students (Adom et al., 2023; King-Sears et al., 2023). Hence, the CAST (2024) questionnaire was administered to ascertain the students' perception and value of UDL as a teaching methodology. Data shown in Table 4 indicates the following results: multiple means of representation (mean=4.29 or 85.8%), multiple means of engagement (mean=4.23 or 86.4%), and multiple means of action and expression (mean=4.28 or 85.6%). Details of the various variables under the three core principles of UDL are presented in **Table 4**.

Table 4: Perception and Value of UDL

Multiple Means of Representation	N	Mean	Median	SD	Min	Max
Perception	100	4.24	4.3	0.326	3.7	5
Language & Symbols	100	4.3	4.3	0.281	3.6	5
Building Knowledge	100	4.32	4.2	0.289	3.8	5
Average Score	100	4.29	4.3	0.214	3.8	4.9

Multiple Means of Engagement	N	Mean	Median	SD	Min	Max
Interest & Identity	100	4.37	4.5	0.317	3.5	5
Effort & Persistence	100	4.33	4.4	0.272	3.6	5
Emotional Capacity	100	4.25	4.2	0.272	3.8	5
Average Score	100	4.32	4.3	0.211	3.8	4.9

Multiple Means of Action and Expression	N	Mean	Median	SD	Min	Max
Interaction	100	4.26	4	0.337	3.5	5
Expression and Communication	100	4.3	4.2	0.286	4	5
Executive Function	100	4.28	4.2	0.253	3.8	4.8
Average Score	100	4.28	4.3	0.204	3.8	4.9

4.2.3 How UDL Shapes Education of Students with Learning Disabilities

Correlation and regression analyses were conducted to ascertain the relationships and impact of UDL on the students' learning outcomes. In Table 5, the results show a significantly positive and strong correlation between UDL principles and students' varied forms of representation ($r(98) = 0.73$, " $p < .001$ "); engagement ($r(98) = 0.75$, " $p < .001$ "); and action and expression $r(98) = 0.71$, " $p < .001$ "). These results as presented in Table 6 to indicate that UDL principles positively and significantly predict students with learning disabilities' learning outcomes through multiple means of representation, engagement, and action and expression, $R = .96$, $F(1, 98) = 1054$, " $p < .001$ with a large effect size ($R = .971$).

Table 5: How UDL Shapes the Education of Students with LDs

Variables		Representation	Engagement	Action & Expression	UDL Principles
UDL Principles	Pearson's r	0.732***	0.749***	0.705***	—
	p-value	< .001	< .001	< .001	—

Table 6: Impact of UDL on Students with Learning Disabilities

Model	R	R ²	F	df1	df2	p
1	0.985	0.971	1054	3	96	< .001

Note. Models estimated using a sample size of N=100

(Source: Field Data, 2025)

4.3 Discussion

The study aimed to ascertain the perceived value of UDL in shaping education for students with learning disabilities in visual arts classrooms. Though the study recorded some underage (below 15 years) and over-aged (19-22 years) participants, the majority of the students were within the stipulated SHS age range of 15-18 years (MoE, 2018). However, the BECE aggregate scores indicated a worrisome trend. Most normative students (aggregate 15-25) fell on the lower end of category B school placement criteria, reflecting how the visual arts programme absorbs students perceived as marginal performers despite qualifying for mainstream SHS education (Babah et al., 2020; Opoku-Asare et al., 2015). The inclusion of students with aggregates 26-30, deemed 'learning disabled' (Zwane & Malale, 2018) and those with 31-40, which is outside category A-C schools and labelled as 'students with SEND' (Lien, 2025; Alghrani et al., 2024), reinforces the stereotype that visual arts is a "last resort" for underperforming students (Kankam et al., 2023). This affirms Baidoo-Anu et al.'s (2022) argument about systemic bias and academic misplacement, which often ignores students' actual interests and strengths. Students' underperformance is commonly linked to one or multiple forms of learning disabilities, a neurodevelopmental disorder that affects performance in both academic and creative tasks (Government of New Brunswick, 2003; U.S. DoE, 2025).

The application of Universal Design for Learning (UDL) principles revealed significant positive outcomes for students with learning disabilities. Rooted in cognitive neuroscience, UDL supports all learners through flexible strategies (CAST, 2024; Rao et al., 2023). In this study, the use of the UDL core principles (multiple means of representation, engagement, and action and expression) promoted accessibility and inclusive participation. Under multiple means of representation, PowerPoint presentations, videos, and printed materials addressed diverse perceptual needs and learning preferences (CAST, 2024; Nave, 2021). This aligns with Almeqdad et al.'s (2023) finding that multimodal instruction enhances comprehension and reduces cognitive load. Statistically, the students rated this principle positively, especially in building knowledge. Under multiple means of engagement, activities involving a sawmill field trip, project work, and personalised tasks stimulated interest and autonomy. These strategies, which honoured the students' identities, promoted intrinsic motivation (Saunders & Wong, 2023; Adler & Kletenik, 2025; Moleko, 2021). For multiple means of action and expression, oral presentations, individual exhibitions, and group displays enabled meaningful demonstration of student learning. This principle received the strongest endorsement, which supports Capp's (2017) idea that promoting diverse output methods reduces barriers and builds agency. It also reflects Hollingshead's (2018) view that experiential learning fosters metacognition and independence.

Correlation analysis revealed that increased use of UDL strategies enhanced engagement, comprehension, and expression for students with learning disabilities. These findings align with the ideas of Rao et al. (2023) that UDL reduces instructional barriers as it addresses learner variability. Regression analysis also confirmed UDL's predictive power, reinforcing the assertion that its neuroscientific foundation addresses the "what," "why," and "how" of learning (CAST, 2024; Rao et al., 2023). Representation supports content access (Nave, 2021), engagement fosters motivation (Saunders & Wong, 2023), and expression allows diverse demonstrations of understanding (Capp, 2017).

5. Conclusion and Further Research

This study set out to explore how Universal Design for Learning (UDL) shapes the educational experience of students with learning disabilities in the visual arts classroom. Rooted in inclusive educational theory and grounded in empirical field data, the study employed a mixed-methods approach to examine the impact of UDL principles on learning outcomes. Through classroom observations, visual documentation, and statistical analyses, the findings revealed that the integration of UDL principles fostered a more inclusive environment, which significantly improved students' learning outcomes and participation. These insights are valuable for visual arts educators, curriculum designers, and inclusive education policymakers to better address learner diversity and promote equitable access to the arts.

Further research could make a comparative analysis of the effectiveness of UDL across disciplines such as science or mathematics. Longitudinal studies may also investigate how sustained UDL practices affect academic growth and emotional well-being. Additionally, the inclusion of teacher and parent perspectives could further broaden the understanding and implementation challenges of UDL, and the systemic support needs to accommodate students with LDs.

References

- Adler, R. F., & Kletenik, D. (2025). Empowering access: Integrating multiple means of engagement when teaching accessible design principles. *Education and Information Technologies*, 1-20.
- Adom, D. (2022). Personal Reflection on Practice as a Basic and Senior High School Teacher Using Gibbs Reflective Model: Universal Design for Learning (UDL) in Focus. *REACH: Journal of Inclusive Education in Ireland*, 35(1), 63-82.
- Adom, D., Abroampa, W. K., Amoako, R., Toquero, C. M., & Kquofi, S. (2023). Towards an Inclusive Pedagogy: Applying the Universal Design for Learning in an Introduction to History of Global Art Course in Ghana. *Journal of Contemporary Issues in Education*, 18(1), 79-97.
- Alghrani, A., Ali, N., Allen, K., Bennett, H., Bengier, L., Betts, J., Bradley, S., Bond, C., van den Bree, M., Brooks, R. & Chawner, S. (2024). An evidence-based plan for addressing the special educational needs and disabilities (SEND) assessment and support crisis. *Child of the North*, 12-46.
- Almeqdad, Q. I., Alodat, A. M., Alquraan, M. F., Mohaidat, M. A., & Al-Makhzoomy, A. K. (2023). The effectiveness of universal design for learning: A systematic review of the literature and meta-analysis. *Cogent Education*, 10(1), 2218191, 1-24.

- Almumen, H. A. (2020). Universal design for learning (UDL) across cultures: The application of UDL in Kuwaiti inclusive classrooms. *Sage Open*, 10(4), 1-14.
- Babah, P. A., Mensah, R. O. & Acquah, A. (2020). Computerized school selection and placement system in Ghana: Challenges and the way forward. *European Journal of Educational Sciences*, 7(2), 70-80.
- Baidoo-Anu, D., Gyamerah, K., & Chanimbe, T. (2022). Secondary school categorization in Ghana: Silent plights of students and implications for equitable learning. *Journal of Human Behavior in the Social Environment*, 33(3), 348–365.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.
- Capp, M. J. (2017). The effectiveness of universal design for learning: a meta-analysis of literature between 2013 and 2016. *International Journal of Inclusive Education*, 21(8), 791–807.
- CAST (2024). *Universal Design for Learning Guidelines version 3.0*. Lynnfield, MA: Author.
- Famolu, F. B. (2020). Identification and Teaching of Students with Specific Learning Disability: Counselling Implications. *TAWARIKH*, 12(1), 93-110.
- Global Initiative for Inclusive Information and Communication Technologies [G3ICT] (2020). Grantees to Implement Universal Design in Ghana's Inclusive Education Policy. February 04, 2020. Retrieved from <https://g3ict.org/headlines/grantees-to-implement-universal-design-in-ghanas-inclusive-education-policy>.
- Government of New Brunswick (2003). *Resource for the Identification and Teaching of Students with Specific Learning Disability: High School Program*. Canada: New Brunswick Department of Education.
- Hollingshead, A. (2018). Designing engaging online environments: Universal design for learning principles. In *Cultivating diverse online classrooms through effective instructional design* (pp. 280-298). United States: IGI Global.
- King-Sears, M. E., Stefanidis, A., Evmenova, A. S., Rao, K., Mergen, R. L., Owen, L. S., & Strimel, M. M. (2023). Achievement of learners receiving UDL instruction: A meta-analysis. *Teaching and Teacher Education*, 122 (103956), 1-15.
- Levey, S. (2023). Universal design for learning. *Journal of Education*, 203(2), 1-58.
- Lien, V. (2025). Decolonising Special Educational Needs and Disabilities (SEND): A Systems Theoretical Framework for Global Inclusivity. *Systems Research and Behavioral Science*, 42(2), 517-530.

Maki, K. E., & Adams, S. R. (2019). A current landscape of specific learning disability identification: Training, practices, and implications. *Psychology in the Schools*, 56(1), 18-31.

Middlesbrough Council (2021). Special Educational Needs and Disabilities (SEND). Retrieved from <https://moderngov.middlesbrough.gov.uk/documents/s13124/Final%20Report%20-%20Special%20Educational%20Needs%20and%20Disabilities%20SEND.pdf>.

Ministry of Education (2018). National Pre-Tertiary Education Curriculum Framework. Accra: National Council for Curriculum and Assessment (NaCCA), Ministry of Education.

Moleko, M. M. (2021). Multiple Means of Engagement Strategies for Maximising the Learning of Mathematics in Pandemic-regulated Classrooms. *International Journal of Learning, Teaching and Educational Research*, 20(8), 68-90.

Nanjundeswaraswamy, T. S., & Divakar, S. (2021). Determination of sample size and sampling methods in applied research. *Proceedings on Engineering Sciences*, 3(1), 25-32.

Nantwi, W. K., Essel, H. B., & Osei-Poku, P. (2023). Assessing Creative Arts Teachers' Competence in the Implementation of Inclusive Creative Arts Education Using Universal Design for Learning Framework. *Africa Development and Resources Research Institute (ADRRRI) Journal (Multidisciplinary)*, 32(2:9), 1-24.

Nave, L. (2021). Universal design for learning: UDL in online environments: The WHAT of learning. *Journal of Developmental Education*, 44(2), 30-32.

NC DPI Exceptional Children Division (2021). Specific Learning Disabilities Policy Fact Sheet #4. Retrieved from <https://www.dpi.nc.gov/sld-fact-sheet-4/download?attachment>,

Niad, H., Aronson-Ensign, K., Affran, A., Hayes, A., Karr, V. & Hayford, S. (2021). Formative Research and Technical Guidance on Identification and Support to Children with Learning Difficulties in Early Grades in Ghana. Final Report. Retrieved from <https://www.unicef.org/ghana/media/4121/file/Universal%20Design%20for%20Learning%20-%20Report.pdf>.

Opoku-Asare, N. A., Tachie-Menson, A., & Essel, H. B. (2015). Perceptions, Attitudes and Institutional Factors That Influence Academic Performance of Visual Arts Students in Ghana's Senior High School Core Curriculum Subjects. *Journal of*

Education and Practice, 6(21), 39-49.

Owiny, R. L., & Hartmann, E. (2020). Designing and Teaching for Student Engagement in Online Courses Through UDL. In *Handbook of Research on Developing Engaging Online Courses* (pp. 314-329). United States: IGI Global.

Rao, K., Gravel, J. W., Rose, D. H., & Tucker-Smith, T. N. (2023). Universal Design for Learning in its 3rd decade: A focus on equity, inclusion, and design. *International Encyclopedia of Education*, 6, 712-720.

Saunders, L., & Wong, M. (2023). Multiple Means of Engagement: Connecting with Students Across Modalities through Choice, Flexibility and Authentic Assessment. In *Proceedings of the ALISE Annual Conference*, 1-2.

Sewell, A., Kennett, A., & Pugh, V. (2022). Universal Design for Learning as a theory of inclusive practice for use by educational psychologists. *Educational Psychology in Practice*, 38(4), 364-378.

Syre-Hager, S. (2022). Supporting Teachers' Understanding and Implementation of Universal Design for Learning (UDL) for Student Engagement through Transformational Leadership: One School's Journey. Doctoral Dissertation, Northeastern University, United States.

Terrell, S. R. (2022). *Writing a proposal for your dissertation: Guidelines and examples*. New York: Guilford Publications.

US Department of Education (2025). Individuals with Disabilities Education Act (IDEA). Retrieved from <https://www.ed.gov/laws-and-policy/individuals-disabilities/idea>.

Zwane, S. L., & Malale, M. M. (2018). Investigating barriers teachers face in the implementation of inclusive education in high schools in Gege branch, Swaziland. *African Journal of Disability*, 7(0), a391, 1-12.

A Proposed Framework For Integrating Artificial Intelligence In Virtual Labs (AI-Vlab): Enhancing Scientific Discovery In Colleges Of Education

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ABSTRACT:

Virtual laboratories (VLab) are increasingly reshaping science education by providing interactive and scalable platforms, especially in contexts with limited access to physical laboratory infrastructure. However, the transformative potential of VLABs remains underutilized without intentional integration with Artificial Intelligence (AI). This study aimed to develop a conceptual framework for AI integration into VLAB (AI-VLAB) to enhance scientific discovery, adaptive learning, and teacher effectiveness in Colleges of Education. Using a design-based research approach, this study critically reviewed existing AI education frameworks and drew on prior work in practical chemistry education. The framework was refined through expert input, simulations, and evaluation of AI-supported virtual labs, focusing on adaptive feedback, ethical use, accessibility, curriculum alignment, and teacher empowerment. The AI-VLAB framework is a context-sensitive model that integrates adaptive feedback, ethical AI applications, curriculum alignment, and teacher training. Linking TPACK and UTAUT with AI tools enhances student engagement, ensures equitable access, and improves science comprehension, offering a scalable solution for educational settings with limited resources. The proposed AI-VLAB framework will empower pre-service teachers through targeted training in AI-driven instructional tools, improved access to virtual experimentation even in low-resource settings, and the institutionalization of ethical standards that guide responsible and scalable AI use in science education. The AI-VLAB framework provides a practical roadmap for integrating AI into VLAB, promoting inclusive, ethical, and future-oriented science education reforms.

KEYWORDS: Artificial Intelligence, Virtual Laboratories, Adaptive Learning, Digital Transformation, Framework

1. Introduction

The rapid evolution of educational technologies has catalysed a transformation in science education, particularly in terms of how laboratory experiences are delivered. While effective, traditional physical laboratories are often constrained by limited infrastructure, cost, and accessibility (Kolil et al., 2020), which are particularly pronounced in educational institutions across developing regions. In response to these limitations, Virtual Laboratories (VLab) have gained prominence as scalable and flexible platforms for facilitating scientific experimentation and enquiry (Zhang et al., 2024; Sellberg et al., 2024). V Labs are computer-based platforms that simulate real laboratory environments, enabling learners to conduct experiments and engage with scientific processes in a safe and interactive manner (Raman et al., 2022). However, many existing VLab platforms remain static and lack the capacity to provide real-time feedback (Kumar et al., 2021; Kok et al., 2021), adapt to learners' needs, or simulate authentic scientific reasoning, thereby limiting their pedagogical potential. Artificial Intelligence (AI) offers an opportunity for education to close this gap by enhancing interactivity, personalization, and data-driven assessment (Samala et al., 2025). Despite this potential, there remains a significant lack of conceptual models or frameworks guiding meaningful integration of AI into VLab environments, especially within the teacher preparation landscape in science education (Aiyedun, 2024). In Ghana, there exist "ICT in Education Policy", embedded within the Education Strategic Plan and Sustainable Development Goals (2018–2030), that aims to align the educational system with evolving national priorities and technological advancements. However, its practical application in science education and teacher preparation in Ghana remains limited (Agyemang et al., 2025), in terms of leveraging AI in laboratory-based science instruction. This policy-practice disconnect highlights the urgent need for innovative frameworks that translate national aspirations into classroom-level transformation. In Ghana, Colleges of Education (COE) serve as the primary institutions for training pre-service teachers, playing a pivotal role in shaping the quality of basic education through structured professional and pedagogical preparation (Tetteh & Agyei, 2022).

In response, this article proposes an AI-VLab framework, a conceptual model for integrating AI technologies into VLab to enhance scientific discovery and enquiry-based learning in Ghana's COE. The framework seeks to foster personalized learning pathways, simulate complex scientific phenomena, and support the development of metacognitive and enquiry skills among pre-service teachers. The

overarching aim is to design a context-relevant, inclusive, and accessible framework that aligns with the goals of 21st-century science education incorporated in the 4-year B.Ed. curriculum.

The specific objectives of this study were as follows:

1. Identify key pedagogical and technological principles that inform AI integration in VLab environments.
2. Develop a conceptual framework for effective and inclusive AI integration in science VLab; and
3. Recommend scalable and instructional strategies for implementation across diverse educational contexts.

To achieve these objectives, this study adopted a Design-Based Research (DBR) approach that involves iterative design, implementation, and refinement of the proposed framework in authentic educational settings. This method allows collaborative engagement with stakeholders, real-time testing of design assumptions, and evidence-based improvements (Parker, 2011). The study is limited by its conceptual scope in this phase, as full empirical validation and large-scale deployment of the framework are reserved for subsequent research. This study contributes to both theory and practice by proposing a conceptual framework that integrates artificial intelligence capabilities with science pedagogy within virtual lab environments. Practically, this study provides actionable insights for curriculum designers, policymakers, and teacher educators seeking to enhance digital science instruction. Ultimately, the AI-VLab Framework is expected to benefit pre-service science teachers, teacher education institutions, and policymakers by fostering innovative, equitable, and evidence-informed science teaching practices.

2. Conceptual Foundations for AI Integration in VLab

The growing interest in AI integration within education has led to a number of frameworks proposing diverse approaches to curriculum transformation, digital tool adoption, and virtual experimentation. These conceptual models offer valuable insights for designing AI-integrated VLabs, particularly in contexts with evolving pedagogical and technological needs. AI integration in education has catalysed efforts to reform the curriculum, pedagogy, and learning environment. Zhou and Schofield (2024) propose a flexible framework to enhance AI literacy in higher education by integrating generative AI (GenAI) tools across disciplines. Grounded in Bloom's taxonomy, this model scaffolds student learning through understanding, application, creation, and ethical evaluation of AI. It includes a pedagogical toolkit

that maps GenAI tools to strategies, such as brainstorming, critical evaluation, and ethical reflection (Laupichler et al., 2022; Ng et al., 2023). While it offers a strong alignment between pedagogy and technology, the framework is limited by its conceptual nature, lack of empirical validation, and underdeveloped considerations of institutional readiness and lifelong learning.

In addition, Ajayi (2023) advanced a model for AI-driven curriculum adaptation in STEM education, emphasizing responsiveness to evolving industry needs. The framework integrates AI technologies, including machine learning and natural language processing, to support dynamic curriculum updates, skill gap analysis, and personalized learning. Drawing on theories such as constructivism and experiential learning, it features tools, such as intelligent tutoring systems. Notable strengths of this study include responsiveness and collaboration. However, challenges, such as faculty resistance, infrastructure gaps, and algorithmic bias, persist. The author calls for studies that evaluate outcomes, safeguards, and inclusive implementation.

Recent advancements in VLab design have produced other conceptual frameworks aimed at integrating AI and digital technologies into science education. Klami et al. (2024) offer a cross-disciplinary framework that merges AI techniques, such as Bayesian optimization and reinforcement learning, with modular software and digital twins to simulate scientific enquiry. Although their emphasis on FAIR data and user personalization is commendable, the framework may lack empirical grounding and overlook ethical and contextual challenges in low-resource settings. Birke-land (2022) introduces a model driven by learning analytics aimed at enhancing collaboration within bioscience virtual laboratories (VLs). This model, grounded in the Learning Analytics Life Cycle, employs dashboards and monitors interaction. However, they are not integrated with mainstream educational platforms and lack automation and scalability. Siddique et al. (2024) highlight the importance of accessibility and curriculum alignment through a lightweight, web-based simulation system that prioritizes interactivity and independence. Nonetheless, this framework is constrained by inadequate analytics, weak pedagogical integration, and lack of evidence-based validation. Collectively, these frameworks provide diverse perspectives on the integration of AI with virtual labs; however, they share common deficiencies in empirical testing, theoretical robustness, and inclusivity. This underscores the necessity of a comprehensive, adaptable model grounded in both pedagogical theory and technological feasibility

Although recent frameworks offer valuable insights into the design of AI-VLab, some theoretical and contextual gaps remain. Most existing models are not anchored in established technology integration theories, such as the Unified Theory of Acceptance and Use of Technology (UTAUT), the Technology Acceptance Model (TAM), or the Technological Pedagogical Content Knowledge (TPACK) framework (Xue & Rashid, 2024; Shambare & Jita, 2024), limiting their generalisability and capacity to inform effective educational implementation. Furthermore, few studies address the specific realities of Ghanaian education systems, where infrastructural limitations, varying levels of digital literacy, and culturally relevant pedagogy shape AI adoption. These factors reduce the pedagogical relevance, equity, and scalability of the current AI-VLab frameworks. In response, this study proposes an inclusive AI-VLab framework, a theoretically grounded and contextually responsive model designed to enhance scientific enquiry and discovery within Ghanaian Colleges of Education.

3. Research Methodology

This study adopts a Design-Based Research (DBR) methodology, recognized for its ability to bridge theory and practice through iterative cycles of design, enactment, analysis, and redesign (Bowler & Large, 2008; Parker, 2011; Wang & Hannafin, 2005). DBR is particularly suitable for the development of context-sensitive solutions in complex educational environments. This approach for conducting design-based research includes (1) analysis of practical problems by researchers and practitioners, (2) development of solutions with a theoretical framework, (3) evaluation and testing of solutions in practice, and (4) documentation and reflection to produce a final framework.

The current phase of the study focused solely on the initial stages, that is, problem analysis and framework design, as outlined in Reeves' (2006) four-phase DBR model. The preliminary analysis examined curriculum alignment, integration of NTCEF and NTS, and articulation of learning outcomes relevant to scientific discovery and expert input. The resulting conceptual framework incorporates four core components: Pedagogical Intent, AI Functional Capabilities, VLab Affordances, and Learner Engagement Pathways (Vaezi et al., 2019; Wang & Hannafin, 2005).

Experts from science and physical education (biology educators, chemistry educators, integrated science educators, and physics educators) and mathematics/ICT departments at education colleges have validated the framework's content and AI tools. The third and fourth phases focused on implementation with continuous evaluation, which will be examined in future research. While DBR acknowledg-

es limitations, such as potential researcher influence and difficulty in defining the end of a design cycle, steps to mitigate these challenges will be integrated during subsequent phases.

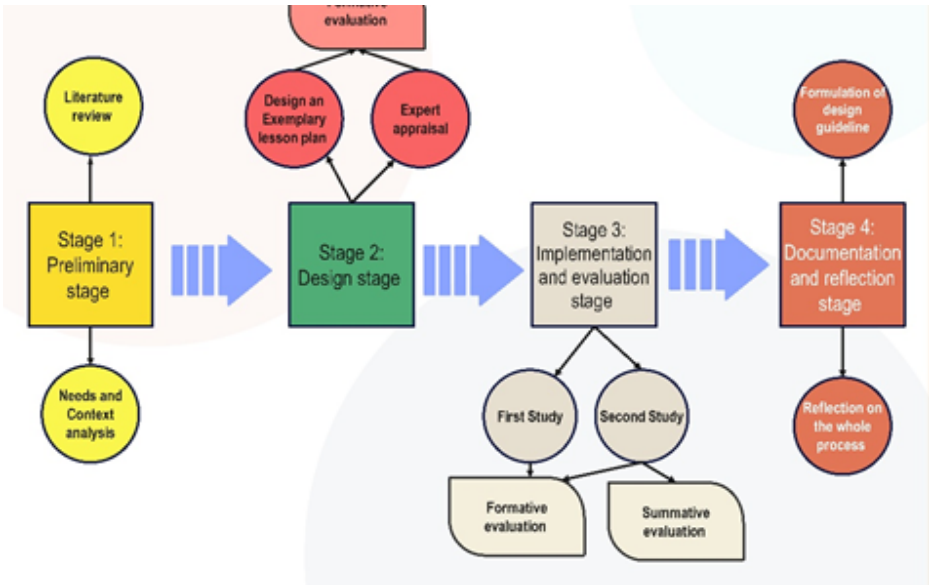


Figure 1. Illustration of the developmental stages design-based research for the study

(Source: Bowler & Large, 2008; Parker, 2011; Reeves, 2006; Wang & Hannafin, 2005)

4. Design of proposed framework

This section outlines the design of the framework for integrating AI with VLab to enhance scientific discoveries in COEs. As future science educators must develop enquiry-based learning competencies, intelligent and adaptive laboratory environments are essential. The proposed framework aligns AI capabilities with pedagogical principles of teacher education. The design process reviewed existing models of technology integration and AI-enhanced learning environments, identifying the core domains: content delivery, adaptive experimentation, real-time feedback, learner support, and ethical considerations. The framework was shaped by priorities such as personalization and data-driven decision-making. The framework centres on four interacting components: (1) Pedagogical Intent, (2) AI Functional Capabilities, (3) VLab affordances, and (4) Learner Engagement Pathways. These components ensure that the AI-VLab is purposefully embedded to enhance scientific thinking and experimentation. The design included feedback loops for learner adaptation and assessment. By providing a structured model, the framework serves as a blueprint for educators and specialists to create more interactive science-learning experiences. The pathway to the final proposed framework also included views and validation from experts from various subject fields related to the framework. This section presents the visual representation of the framework and its relevance to teacher education.

4.1 Framework conception stage

This phase marks the foundational stage in developing an AI-VLab framework for the teaching and learning of scientific concepts, both theoretically and practically. As emphasized in the design-based research literature, the initial design phase is critical for defining the objectives, scope, and theoretical grounding of an innovation through collaboration among educators, researchers, and practitioners (Bowler & Large, 2008). In line with Parker (2011), this phase involved an extensive review of existing pedagogical models, AI functionalities, and technological infrastructure to ensure the relevance, practicality, and responsiveness of the framework to educational needs. Particular emphasis was placed on integrating key design principles, such as learner engagement, adaptability, and accessibility components, widely acknowledged in DBR as essential for producing usable and scalable educational interventions. Thus, this conception stage sets a theoretically informed groundwork for further development, empirical validation, and real-world classroom applications.

4.2 Conceptualisation of key concepts for the framework

This AI-VLab framework is categorised into the levels of build. In defining key concepts for the framework, AI's roles in VLab were identified, including adaptive learning technologies to personalise experiences, intelligent virtual assistants for real-time feedback, and enhanced simulations for conducting complex experiments. These considerations were aligned with accessibility, usability, scalability, and cost-effectiveness to ensure practical and inclusive design. Some of them include educational goals, learning outcomes and discovery, AI functions and capabilities in VLab, User interaction and competences, pedagogical alignment, infrastructural support, ethical considerations, and assessment.



Figure 2. Key Areas for Consideration in the Proposed Framework

(Source: From authors' own creation)

4.3 Structure of the framework

The AI-VLab framework is structured to address multiple dimensions of educational design and implementation. It emphasises enhancing user readiness, aligning with vigorous pedagogical practices, and incorporating advanced AI capabilities, such as adaptive learning and simulation tools. Designed with scalability, accessibility, and ethical considerations in mind, the framework spans six levels, covering essential aspects such as curriculum integration, theoretical underpinnings, and continuous assessment. This approach ensures an inclusive practical design that fosters scientific discovery, critical thinking, and meaningful educational outcomes. The framework was “built” on six (6) defined levels that included

- Level 1: Users and Competence
- Level 2: Curriculum and Pedagogical alignment
- Level 3: Theoretical foundations
- Level 4: AI integrated VLab (AI-VLab)
- Level 5: Ethical and Inclusive Design
- Level 6: Assessment and Continuous Improvement

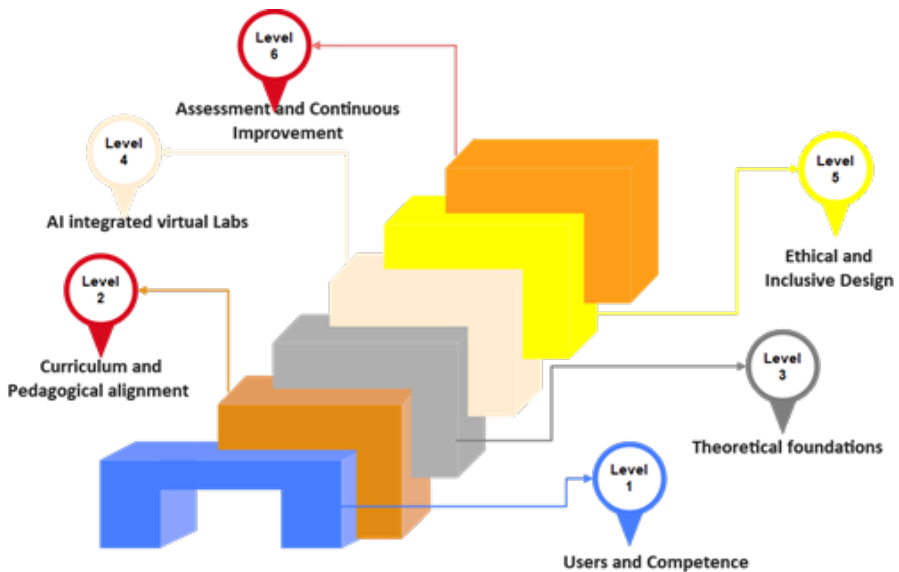


Figure 3. Skeletal Structure Of The Framework Based On The Levels

(Source: From authors' own creation)

The proposed AI-VLab framework interconnects levels to address critical aspects of its implementation. These levels guide the systematic development of AI-driven V Labs to enhance scientific discoveries in COE. This framework captures the relationship between technology, pedagogy, institutional capacity, and user competence, ensuring a holistic approach that meets the science education needs of Ghana's teacher-training institutions.

4.3.1 Users and Competence (Level 1)

This level plays a foundational role in the framework by establishing the central context for implementing AI-driven virtual labs (VLab) within Colleges of Education (COEs) in Ghana. It focuses on understanding key users, such as educators and pre-service teachers, by assessing their pedagogical content knowledge, digital literacy, and competencies in AI usage. Drawing on established models, such as the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), this level evaluates critical factors, such as perceived usefulness, perceived ease of use, performance expectancy, and effort expectancy, to measure user readiness for AI integration (Xue & Rashid, 2024). These models offer structured insights into users' readiness to adopt technology, helping identify attitudinal, motivational, and contextual barriers. Simultaneously, the integration of pedagogical content knowledge (PCK) ensures that technology adoption is not only feasible but also pedagogically meaningful (Shambare & Jita, 2024) for aligning AI tools with content delivery and instructional goals. By examining technology familiarity, behavioural intention to use AI, and adaptability to digital environments, the framework ensures that implementation aligns with Ghanaian COEs' technological capacities and educational realities. This level addresses the challenges in low-resource contexts by identifying skill gaps and fostering digital literacy. It also supports user-centred AI solutions that enhance curricular alignment and capacity building in science education.

4.3.2 Curriculum and Pedagogical alignment (Level 2)

The integration of artificial intelligence into virtual laboratories (AI-VLab) must be aligned with the principles of the new 4-year Bachelor of Education (B.Ed.) curriculum to ensure that pre-service teachers are equipped with the skills and knowledge required for effective scientific instruction and enquiry. This framework emphasises not only alignment with curriculum objectives but also the deliberate blending of technological, pedagogical, and content knowledge (TPACK) to support meaningful learning experiences. The TPACK framework provides a critical lens for ensuring that AI tools in VLab environments are not merely technological add-ons,

but are purposefully integrated to enhance content knowledge, support appropriate instructional strategies (Pedagogical Knowledge), and Technological Knowledge (Latip et al., 2023) in leveraging digital tools. AI-enhanced VLab environments guided by TPACK principles support adaptive instruction through intelligent tutoring systems, simulations, and data analytics (Shambare & Jita, 2024). These features enable pre-service teachers to connect theory with practice by experimenting with safe virtual spaces that replicate scientific processes. This integration supports various assessment methods in B.Ed. curriculum, offering AI tools for formative assessments, performance tracking, and evaluation. AI-VLab fosters enquiry-based learning and critical thinking through problem-centred tasks aligned with constructivist approaches. This level ensures AI integration reflects national teacher standards by aligning with the National Teacher Education Curriculum Framework (NTCEF) and National Teachers' Standards (NTS) which guide curriculum implementation, subject expertise, instructional competence, and reflective practices. By embedding TPACK-informed AI tools in VLab, this framework promotes digitally fluent educators who can navigate 21st-century classrooms, while advancing scientific discovery and pedagogical innovation.

4.3.3 Theoretical foundations (Level 3)

A robust framework for integrating AI into VLab must be anchored in educational theories that shape teaching and learning experience. This level establishes theoretical underpinnings that guide AI-enhanced scientific discovery, ensuring that implementation aligns with proven instructional models. Two key theoretical approaches considered are Constructivist Learning Theory and the TPACK Model. Constructivism posits that learners actively construct knowledge through experiences, interactions, and problem solving, rather than passively absorbing information (Behnagh & Yasrebi, 2020). AI-powered VLab naturally lean towards constructivist environments by allowing learners to interact with simulated scientific phenomena, manipulate variables, and receive real-time feedback. These experiences enable student teachers to internalise scientific concepts through their discovery and enquiry. AI-VLab reinforces constructivist principles by enabling students to engage in scientific enquiry, simulation, and exploration. Through adaptive learning technologies, students interact with models, conduct virtual experiments, receive feedback, and foster critical thinking skills. AI facilitates collaborative learning, allowing students to analyse scientific phenomena, test hypotheses, and refine their understanding.

The TPACK framework guides student teachers to meaningfully engage with AI-VLab in science teaching practices. For Technological Knowledge (TK), student teachers use intelligent tutoring systems to guide learners through virtual experiments or to analyse student performance using AI-generated dashboards. They have gained experience with simulation tools and real-time feedback systems that replicate laboratory conditions (Latip et al. 2023). For Pedagogical Knowledge (PK), student teachers apply enquiry-based learning by designing AI-VLab activities in which learners investigate scientific problems, receive automated scaffolding prompts, and collaborate in virtual environments. These tools support differentiated instruction by adapting tasks to student performance levels. Regarding Content Knowledge (CK), AI-VLab allows student teachers to teach complex topics through interactive visualisations and simulations. They used AI-powered tools to help students design hypotheses, interpret results, and connect theoretical concepts to practical outcomes. These experiences with AI-VLab reflect how science teachers can meaningfully integrate technology (Shambare & Jita, 2024), even in resource-constrained contexts. Through these applications, student teachers master digital tools while learning to integrate them into pedagogically sound science instruction. By integrating these underpinnings into the proposed AI-VLab, CoEs can foster scientific engagement, improve technological proficiency, and enhance enquiry-based learning, thus preparing pre-service teachers for science education in the digital age.

4.3.4 AI integrated virtual Labs (Level 4)

Before integrating AI-driven components into VLab, it is essential to first determine the type of VLab environment that best aligns with the needs of student teachers within the COE context. The selection of VLab, whether 3D immersive simulations, 2D interactive models, online-based labs, or real-time feedback-enabled systems sets the foundation for AI integration by establishing the technological framework within which AI functions (Klami et al., 2024). Once the VLab type is selected based on contextual needs, such as Internet accessibility, device availability, and user competence, the integration of AI-enabled components can be appropriately tailored (Aiyedun, 2024). This ensures that features, such as intelligent experimentation engines and adaptive feedback modules, are embedded to align with the chosen lab format. Establishing this order promotes coherence between technological design and pedagogical intent, ensuring that AI tools function effectively in virtual environments. This logical order enables optimal compatibility and pedagogical alignment, allowing AI to enrich VLab experiences while maintaining its curriculum goals (Samala et al., 2025).

4.3.4.1 Selection of VLab Types

The effectiveness of AI-VLab implementation is strongly influenced by the type of lab environment selected, which must align not only with infrastructural conditions and pedagogical goals but also with users' technological competence and readiness, as assessed in Level 1. According to the UTAUT framework, factors such as performance expectancy, effort expectancy, social influence, and facilitating conditions shape user acceptance and use of technology. Therefore, the choice between 3D immersive simulations, 2D interactive environments, online-based labs, or real-time feedback systems should consider how these formats meet the perceived usefulness and ease of use for educators and pre-service teachers. When users believe that a particular VLab format will enhance teaching effectiveness with manageable effort, they are more likely to adopt it (Agyemang et al., 2025). Thus, selecting an appropriate VLab environment that matches users' competencies and expectations ensures that AI functionalities are integrated to promote engagement, usability, and pedagogical effectiveness. Below are some suggestions that may determine the selection of VLab type.

- **3D VLab:** Provides highly immersive simulated experiments, allowing student teachers to engage with lab equipment and conduct investigations in realistic digital environments. They are ideal for deep experiential learning and complex scientific demonstrations.
- **2D VLab:** Offers more straightforward interactive models to student teachers with essential functionalities for concept visualization and basic experimentation, often requiring less computational power.
- **Online-Based/Real-Time Feedback Systems:** Online-based virtual labs supported by AI allow student teachers to conduct experiments remotely while receiving real-time feedback and guidance. These systems use AI to analyse student performance, provide instant corrections and personalized suggestions, and track progress, making science learning more interactive, flexible, and responsive to individual needs.

Once the appropriate VLab is selected, it will ensure that AI-driven scientific discovery aligns with curriculum requirements, enhances pedagogical effectiveness, and supports diverse learning outcomes demanded by the pre-service teachers in the CoEs.

4.3.4.2 VLab Components

AI-enabled components are crucial. It operationalizes the VLab environment and transforms it into a dynamic intelligent learning space. These components function as the main technological pillars that enable science teaching and learning to be more interactive, personalized, and data-informed in educational colleges (Bonney et al., 2022; Naah et al., 2021). Each component plays a distinct role in the transformation of traditional laboratory activities into dynamic, adaptive, and data-driven processes. The components of a VLab, such as AI feedback tools, simulation engines, or learning dashboards, must be technically and pedagogically compatible with the VLab environment chosen. The VLab type sets the foundation for what is possible, while the components operationalise their educational value. Some of these can be listed as follows:

a. Intelligent Experimentation Engine: This AI-powered module guides scientific enquiry by assisting students in formulating hypotheses, designing experiments, and analysing results. It employs simulation-based modelling and predictive analytics to help students explore complex scientific phenomena and provide interactive and exploratory learning opportunities.

b. Adaptive Feedback Module: AI ensures real-time corrections and personalized suggestions during the experiment. This component monitors student responses, offers instant guidance to refine their approach, corrects misconceptions, and deepens understanding. Through adaptive learning, students receive tailored feedback based on their individual learning style and pace.

c. Conceptual Understanding Tracker: Using Natural Language Processing (NLP), this tool analyzes student reflections and responses to assess their depth of comprehension. Tracking learning patterns helps educators to determine whether students grasp fundamental concepts or require additional instructional support. This AI-driven insight enhances students' engagement with scientific content.

d. Pedagogical Analytics Dashboard: This component visualizes student progress through data-driven insights, assisting educators in identifying strengths, weaknesses, and learning trends. AI aggregates performance metrics, allowing instructors to refine teaching strategies, adjust instructional methods, and ensure that students meet key learning objectives.

e. Collaboration and Reflection Support: AI enhances peer interaction and metacognition by facilitating collaborative learning experiences. It supports virtual group discussions, shared experiment analysis, and interactive study sessions, where students collectively reflect on their findings. AI-powered reflection tools

guide students to articulate their thought processes and foster critical thinking and knowledge-building. Birkeland, 2022 ; Klami et al., 2024 ; Kumar et al., 2021 ; Samala et al., 2025)

4.3.5 Ethical and Inclusive Design: Contextual Layer (Level 5)

For the successful integration of AI VLab, key enabling conditions must be established to ensure accessibility, ethical implementation, and effective faculty adoption. This level focuses on the infrastructural needs and capabilities of CoEs as well as the ethical and professional considerations required for sustainable AI-enhanced scientific discovery (Skulmowski, 2023). These conditions directly impact student teachers by creating environments in which they can practically engage with AI-driven simulations, conduct virtual experiments, and receive real-time feedback as part of their training (Eden et al., 2024). For example, access to reliable infrastructure and trained faculty allows student teachers to practice designing lessons using AI tools, interpret data through pedagogical dashboards, and apply AI-supported experimentation in science classroom skills essential for modern teaching and enquiry-based learning required during lessons. Some of these considerations are as follows:

- i. **Infrastructure and Accessibility:** A strong technological foundation is necessary to support VLab environments, including stable internet connectivity, adequate computing resources, and software platforms that can run AI-enhanced simulations. Ensuring equitable access to AI-driven labs, particularly for institutions in underserved regions, is critical for bridging the digital divide and promoting inclusive scientific education (Eden et al., 2024).
- ii. **Ethical AI and Data Privacy:** The responsible use of AI-VLab requires adherence to ethical principles and data protection regulations. AI-driven experimentation involves student data collection, adaptive feedback mechanisms, and AI analytics, thus necessitating safeguards to ensure privacy, security, and transparency. Policies must be established to mitigate biases in AI algorithms, prevent data misuse, and uphold fairness in scientific exploration (Caccavale et al., 2022; Skulmowski, 2023).
- iii. **Faculty Training and Curriculum Integration:** Successful AI integration depends on faculty competence in effectively utilising AI VLab. Educators require professional development programs to familiarize themselves with AI-driven tools, data analytics, and adaptive learning technologies. Additionally, AI must

be seamlessly embedded into the curriculum to ensure that its use supports pedagogical objectives and enhances enquiry-based scientific discovery rather than becoming an isolated technological addition (Eden et al., 2024).

Even well-designed AI systems may fail to achieve their intended impact in the absence of supportive conditions. Consequently, this level ensures that the framework is firmly anchored in the practicalities of institutional readiness, policy coherence, and ethical application of technology.

4.3.6 Assessment and Continuous Improvement (Level 6)

The final level of the framework emphasizes the importance of recurring assessment and continuous improvement to ensure that AI-integrated VLab remain effective, relevant, and responsive to the evolving needs of science education (Alharbi, 2024). This level involves systematic evaluation of both learner outcomes and system performance using quantitative and qualitative data. This will ensure that the AI VLab remains adaptive, data-informed, and responsive to both student learning outcomes and pedagogical effectiveness. The assessment and improvement can be done at three (3) levels namely, users (pre-service teachers or direct beneficiaries), AI-VLab model calibration, and policy or curriculum reviews.

- **Student and Faculty Feedback systems:** Effective AI-VLab must embed mechanisms for continuous assessment and improvement, ensuring that learning outcomes and system usability evolve over time. These mechanisms should leverage automated analytics, feedback loops, and AI-driven assessments to monitor student understanding in real-time (Sajja et al., 2025). Through these tools, educators can track knowledge retention, conceptual mastery, and problem-solving skills, thus enabling timely interventions. The design and implementation of these assessment systems should be informed by technology acceptance models such as TAM or UTAUT. By prioritising perceived usefulness, ease of use (TAM), performance expectancy, effort expectancy, and facilitating conditions (UTAUT), the framework ensures that educators and learners readily adopt VLab tools. This alignment enhances the user experience and enables iterative refinement, where data-driven insights provide updates to content, design, and AI functionality, ensuring effectiveness in science education.
- **AI Model Calibration:** Continuous monitoring of AI algorithms ensures that biases are minimized, predictions remain accurate, and automated feedback remains reliable. This can be achieved using well-trained technicians or faculty members. A regular updates and refinements to AI-driven functionalities can

help optimize experiment simulations, data analysis tools, and collaboration frameworks, improving overall learning experiences (Jumreornvong et al., 2025)

- **Curriculum Alignment and Policy Review:** To sustain the academic relevance of AI-VLab, periodic curriculum alignment reviews are necessary to assess its compatibility with educational standards, faculty expectations, and institutional objectives. AI-powered labs should continuously evolve to support emerging pedagogical approaches, national curriculum frameworks, and competency-based learning outcomes. Moreover, ethical considerations regarding AI governance, data privacy, and security policies must be regularly revised (Johnson et al., 2020) to safeguard responsible AI implementation. Establishing transparent and ethical AI guidelines ensures that V Labs uphold student data protection, algorithmic accountability, and fair access to digital learning tools

By integrating assessment and continuous improvement into the framework, an AI-driven VLab develops into intelligent, adaptive, and student-centred ecosystems that advance scientific discovery within Colleges of Education.

4.4 Validation by Experts

The proposed AI-VLab framework was reviewed and validated by subject matter experts from Colleges of Education, including biology, chemistry, physics, integrated science, mathematics, and ICT educators. Their insights ensured the framework's contextual relevance, alignment with curriculum standards, and practical applicability for enhancing science teaching and learning through AI integration. This paved the way for the finalisation of the proposed framework, as shown in figure 4.

4.5 Final presentation of the proposed AI-VLab framework

To provide a holistic view of the proposed AI-VLab framework, the levels were synthesised into a graphical representation that illustrates their structure and interconnections. It presents a conceptual framework for integrating AI into VLab to enhance scientific discovery and learning outcomes in Colleges of Education. Central to the framework is the "Users and Competence" level, representing student teachers in the Ghanaian context, whose development is aligned with NTS and the NTCEF. Connected to this core are components such as curriculum and pedagogical alignment, which ensure that AI integration complements the current educational goals. The types of AI-VLab may include virtual reality, 3D, 2D, online, and device-based environments that form an integral layer, allowing diverse and accessible learning experiences. These are underpinned by theoretical foundations, particularly Constructivist Learning Theory and the TPACK model, which justify the use of AI to support active enquiry-based science teaching. Ethical and inclusive design, along with assessment and continuous improvement, serves as a guiding principle, ensuring sustainability, accountability, and alignment with best practices in AI use and educational equity.

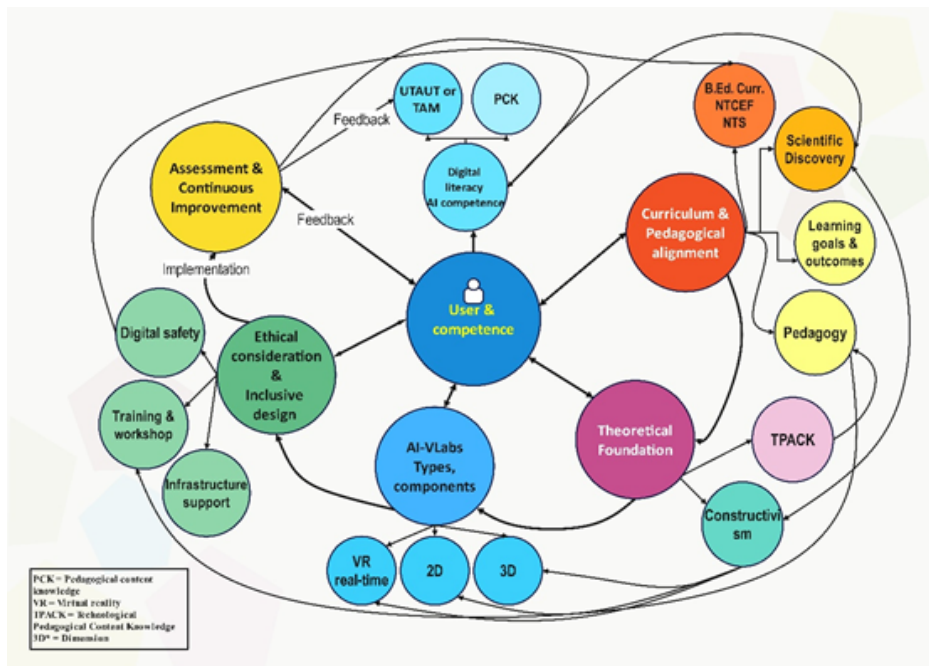


Figure 4. A graphical representation of the proposed AI-VLab framework
 (Source: Authors' own creation)

4.6 Suggested steps for Continuous Assessment and Improvement of the Framework

It is important to conduct a periodic assessment of the impact of the framework, and thus, the need to improve where necessary. The authors propose these steps to help evaluate the framework and its impact. These suggested steps can begin by setting up a baseline for outcomes or goals to establish a feedback loop that will help institutionalise this means of assessment process. These steps constitute a critical component of the process designed to guide Stages 3 and 4 of the research, specifically involving pilot testing, documentation, reflection, and refinement of the framework.

Step 1 - Establishing key performance indicators (KPIs):

Establishing clear learning objectives and performance indicators, such as conceptual understanding, problem-solving, and user engagement, is essential. Institutions should also define their goals for AI integration, such as improving student enquiries or enhancing digital competence, while using pre-implementation data to set a baseline for future comparisons.

Step 2: Develop Assessment Instruments and Tools for regular feedback collection:

To ensure continuous improvement, institutions should implement student and faculty surveys to assess usability and effectiveness, gather real-time feedback through AI-driven analytics tracking learning progress and engagement, and conduct focus group discussions with educators to address implementation challenges. These tools can be developed from adoption frameworks like UTAUT, TAM etc to put the feedback into proper context.

Step 3 - Analysis, optimisation of the AI model, and system calibration:

Once user feedback is established, educators can focus on calibrating the adopted AI models or tools. Mechanisms were implemented to ensure minimal bias detection. This refinement improves the algorithm and prediction accuracy of the personalized feedback. When users change, learning settings should be adapted to accommodate diverse learner needs and align AI functionalities with curriculum standards. This ensures that technology remains effective, inclusive, and pedagogically relevant.

Step 4–Organisation of periodic professional development sessions:

To ensure effective continuous improvement in the integration of AI tools, institutions should conduct PD sessions that are specifically designed for AI competency building for educators and establishing peer-led faculty collaboration networks to share best practices. This can encourage faculty-led AI research initiatives involving educators, IT staff, and curriculum experts to foster innovation. These efforts can help identify areas that require refinement, thereby enhancing the overall application of AI in various institutions.

Step 5 - Implement Iterative Improvements and Sustain the Feedback Roadmap:

Assessment findings should directly inform refinements to AI functionalities and enhance instructional design, improving learner outcomes. Effective practices can be scaled across CoEs to ensure their consistency and quality. To sustain progress, colleges can establish regular reviews (termly or annually) and broaden stakeholder involvement, including student teachers and practicum supervisors. These insights can guide curriculum updates and policy decisions by reinforcing a continuous feedback loop. (Johnson et al., 2020 ; Sajja, et al., 2025)

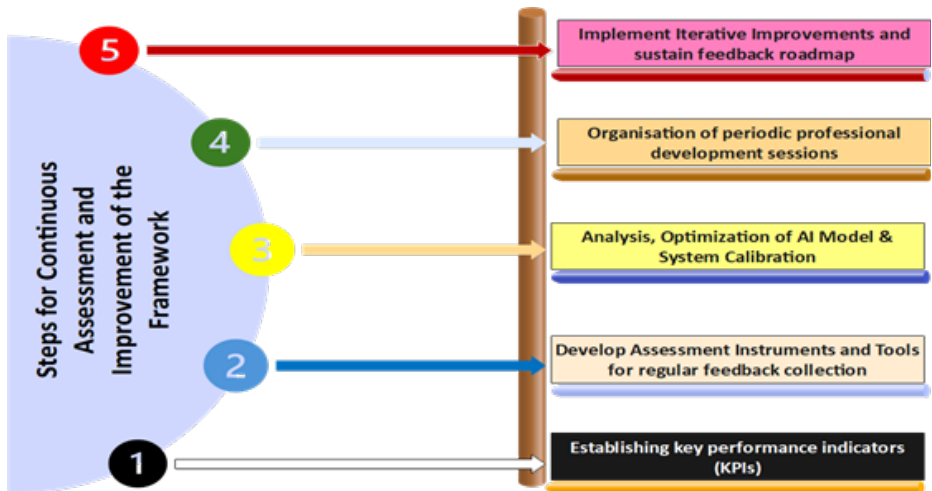


Figure 5. Graphical representation of the steps involved in assessment and continuous improvement of the AI-VLab framework stage.

(Source: Authors' own creation)

5. Conclusion and Further Research

This paper proposes the AI-VLab framework as a conceptual model for integrating AI into VLab, specifically within the context of Colleges of Education. Stemming from the increasing demand for innovative science education practices and the limitations of traditional laboratory access, this framework responds to the need for inclusive and contextually relevant solutions. The AI-VLab framework is grounded in its design in pedagogical theory and the alignment of AI functionalities with learner autonomy, assessment, and instructional feedback. It provides a practical roadmap for enhancing scientific discovery and self-learning in teacher education through AI-driven virtual laboratories that support pre-service teacher training engagement.

Further research will involve piloting and refining the AI-VLab framework across selected Colleges of Education. This includes empirical testing of its impact on learner outcomes, integration with pedagogical models such as TPACK and UTAUT, and the development of adaptive learning capabilities. Future studies will explore the potential of the framework for collaborative learning, accessibility, and ethical data use in AI personalization. These steps will help to establish a robust and scalable model for AI integration in virtual science education.

6. References

- Abisoye, A., (2023). 'Developing a Conceptual Framework for AI-Driven Curriculum Adaptation to Align with Emerging STEM Industry Demands'. <https://doi.org/10.54660/IJMRGE.2023.4.1.1074-1083>
- Agyemang, A. K. Y., Ossei-Anto, T. A., & Acheampong, A., (2025). 'Exploring factors influencing the acceptance of dry lab technologies in Ghanaian senior high schools: IPMA insights on the influence of technology familiarity'. *Journal of Research in Science, Mathematics and Technology Education*, 8(SI), 103-134. <https://doi.org/10.31756/jrsmte.415SI>
- Aiyedun, T. G. O. (2024). 'Artificial Intelligence (AI) In Education: Integration Of AI Into Science Education Curriculum In Nigerian Universities'. *International Journal of Artificial Intelligence for Digital Marketing*, 1(1), 1–14. <https://doi.org/10.61796/ijaifd.v1i1.13>
- Alharbi, N. S. (2024). 'Evaluating competency-based medical education: A systematized review of current practices'. *BMC Medical Education*, 24(1), 612. <https://doi.org/10.1186/s12909-024-05609-6>
- Birkeland, H., (2022). 'Understanding collaboration in virtual labs: A learning analytics framework' (Master's thesis, The University of Bergen). <https://hdl.handle.net/11250/3001938>
- Bonney, E. A., Budu, G. B., Dzidzinyo, A. F., Dah, E. M., & Klutse, G. Y. (2022). 'Resourcefulness In Science Teaching And Learning In The Colleges Of Education In Ghana: A Systematic Literature Review'. *American Journal of Education and Practice*, 6(1), 11–35. <https://doi.org/10.47672/ajep.982>
- Bowler, L. and Large, A., (2008). 'Design-based research for LIS'. *Library & Information Science Research*, 30(1), pp.39-46. <https://doi.org/10.1016/j.lisr.2007.06.007>
- Caccavale, F., Gargalo, C. L., Gernaey, K., & Krühne, U. (2022). 'To be fAIr: ethical and fair application of artificial intelligence in virtual laboratories.' In *Towards a new future in engineering education, new scenarios that european alliances of tech universities open up* (pp. 1022-1030). Universitat Politècnica de Catalunya. <http://dx.doi.org/10.5821/conference-9788412322262.1398>
- Eden, C. A., Chisom, O. N., & Adeniyi, I. S. (2024). 'Integrating AI in education: Opportunities, challenges, and ethical considerations'. *Magna Scientia Advanced Research and Reviews*, 10(2), 006-013. <https://doi.org/10.30574/msarr.2024.10.2.0039>

- Feyzi Behnagh, R., & Yasrebi, S. (2020). 'An examination of constructivist educational technologies: Key affordances and conditions'. *British Journal of Educational Technology*, 51(6), 1907-1919.
- Iiyoshi, T., Hannafin, M.J. and Wang, F., (2005). 'Cognitive tools and student-centred learning: rethinking tools, functions and applications'. *Educational Media International*, 42(4), pp.281-296. <https://doi.org/10.1080/09523980500161346>
- Johnson, C. E., Boon, H. J., & Thompson, M. D. (2020). 'Curriculum alignment after reforms: A systematic review with considerations for Queensland pre-and in-service teachers'. *Australian Journal of Teacher Education (Online)*, 45(11), 34-55.
- Jumreornvong, O., Perez, A. M., Malave, B., Mozawalla, F., Kia, A., & Nwaneshiudu, C. A. (2025). 'Biases in Artificial Intelligence Application in Pain Medicine'. *Journal of Pain Research*, 18. <https://doi.org/10.2147/jpr.s495934>
- Khalil, M. and Ebner, M., (2015). 'Learning analytics: principles and constraints'. In *Edmedia+ innovate learning* (pp. 1789-1799). Association for the Advancement of Computing in Education (AACE). Retrieved June 4, 2025 from <https://www.learn-techlib.org/primary/p/151455/>
- Klami, A., Damoulas, T., Engkvist, O., Rinke, P. and Kaski, S., (2024). 'Virtual laboratories: Transforming research with AI'. *Data-Centric Engineering*, 5, p.e19. <https://doi.org/10.1017/dce.2024.15>
- Kok, Y. Y., Er, H. M., & Nadarajah, V. D. (2021). 'An analysis of health science students' preparedness and perception of interactive virtual laboratory simulation'. *Medical Science Educator*, 31(6), 1919-1929. <https://doi.org/10.1007/s40670-021-01364-1>
- Kolil, V.K., Muthupalani, S. and Achuthan, K., 2020. 'Virtual experimental platforms in chemistry laboratory education and its impact on experimental self-efficacy'. *International Journal of Educational Technology in Higher Education*, 17(1), p.30. <https://doi.org/10.1186/s41239-020-00204-3>
- Kumar, R., Neha, K., & Dwivedi, V. K. (2021). 'Virtual Laboratories as Interactive E-Learning Resources: Benefits and Limitations'. *International Journal for Research in Applied Science and Engineering Technology*, 9(12), 1621-1625. <https://doi.org/10.22214/ijraset.2021.39571>
- Latip, A., Robandi, B., Amaliah, A., Khakim, R. R., & Fatonah, N. (2023). 'Technological Pedagogical Content Knowledge (TPACK) Framework for Science Teachers' Competences in Facing Global Challenges and Issues: A Narrative Literature

Review'. *International Journal of Pedagogy and Teacher Education*, 7(1), 45-57. <https://doi.org/10.20961/ijpte.v0i0.74699>

Laupichler, M.C., Aster, A., Schirch, J. and Raupach, T., (2022). 'Artificial intelligence literacy in higher and adult education: A scoping literature review'. *Computers and Education: Artificial Intelligence*, 3, p.100101. <https://doi.org/10.1016/j-caeai.2022.100101>

Naah, A. M., Agyemang, A. Y. K., Owusu Ansah, F., Samari, J. A., Opuku Acheampong, L., Owusu, M., Kwaah, O. K., Osei Yaw, R., Mensah, T. K., Amuda, T. Y., & Osei-Himah, V. (2021). 'Developing A Conceptual Framework for Science Teaching at Colleges of Education in Ghana'. *European Journal of Education and Pedagogy*, 2(6), 13–18. <https://doi.org/10.24018/ejedu.2021.2.6.190>

Ng, D.T.K., Leung, J.K.L., Su, J., Ng, R.C.W. and Chu, S.K.W., (2023). 'Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world'. *Educational technology research and development*, 71(1), pp.137-161. <https://doi.org/10.1007/s11423-023-10203-6>

Parker, J., (2011). 'A design-based research approach for creating effective online higher education courses'. In 26th Annual Research Forum (Western Australian Institute for Educational Research Inc) Educational Possibilities. 2011 Western Australian Institute for Educational Research Inc.

Raman, R., Achuthan, K., Nair, V. K., & Nedungadi, P. (2022). 'Virtual Laboratories-A historical review and bibliometric analysis of the past three decades'. *Education and information technologies*, 27(8), 11055-11087. <https://doi.org/10.1007/s10639-022-11058-9>

Reeves, T. (2006). 'Design research from a technology perspective'. In *Educational Design Research*. 64-78)

Sajja, R., Sermet, Y., & Demir, I. (2025). 'End-to-end deployment of the educational AI hub for personalized learning and engagement: A case study on environmental science education'. *IEEE access*. <https://doi.org/10.1109/ACCESS.2025.3554222>

Samala, A. D., Rawas, S., Wang, T., Reed, J. M., Kim, J., Howard, N. J., & Ertz, M. (2025). 'Unveiling the landscape of generative artificial intelligence in education: a comprehensive taxonomy of applications, challenges, and future prospects'. *Education and Information Technologies*, 30(3), 3239-3278.

- Sellberg, C., Solberg, M., & Nazari, Z. (2024). 'Virtual Laboratories in STEM Higher Education: A Scoping Review'. *Nordic Journal of Systematic Reviews in Education*, 2. <https://doi.org/10.23865/njsre.v2.5766>
- Shambare, B., & Jita, T. (2024). TPACK: a descriptive study of science teachers' integration of the virtual laboratory in rural school teaching. *Cogent Education*, 11(1), 2365110. <https://doi.org/10.1080/2331186X.2024.2365110>
- Siddique, I.M., Arde, R.A. and Siddique, A.A., (2024). 'The Future of Distance Learning: Streamlined Labs in Virtual Education'. *Journal of IoT and Machine Learning*, 1(1), pp.30-37. <https://doi.org/10.48001/JoITML.2024.1130-37>
- Skulmowski, A. (2023). 'Ethical issues of educational virtual reality'. *Computers & Education: X Reality*, 2, 100023. <https://doi.org/10.1016/j.cexr.2023.100023>
- Tetteh, H., & Agyei, D. (2022). 'Factors Influencing Pre-Service Teachers' Performance in Mathematics in Colleges of Education: Re-counting Experiences in Ghana'. *African Journal of Educational Studies in Mathematics and Sciences*, 18(1), 69–86. <https://doi.org/10.4314/ajesms.v18i1.6>
- Vaezi, H., Moonaghi, H. K., & Golbaf, R. (2019). 'Design-Based Research: Definition, Characteristics, Application and Challenges'. *Journal of Education in Black Sea Region*, 5(1), 26-35. <https://doi.org/10.31578/jebss.v5i1.185>
- Wang, F., & Hannafin, M. J. (2005). 'Design-based research and technology-enhanced learning environments'. *Educational technology research and development*, 53(4), 5-23. <https://doi.org/10.1007/BF02504682>
- Xue, L., Ouyang, S., & Rashid, A. M. (2024). 'The Unified Theory of Acceptance and Use of Technology (UTAUT) in Higher Education: A Systematic Review'. *Sage Open*, 14(1). <https://doi.org/10.1177/21582440241229570>
- Zhang, Y., Chu, Y., Sun, D., Xu, J., Zheng, Y., & Yang, Y. (2024). 'Virtual Laboratories In Science Education: Unveiling Trajectories, Themes, And Emerging Paradigms (2013-2023)'. *Journal of Baltic Science Education*, 23(5), 990–1009. <https://doi.org/10.33225/jbse/24.23.990>
- Zhou, X. and Schofield, L., (2024). 'Developing a conceptual framework for Artificial Intelligence (AI) literacy in higher education'. *Journal of Learning Development in Higher Education*, (31). <https://doi.org/10.47408/jldhe.vi31.1354>

Teachers' Experiences Of Educational Technology For SDG4 In Basic Schools In Asante Akim Central Municipality

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ABSTRACT:

This study investigates teachers' experiences with educational technology (EdTech) in basic schools within the Asante Akim Central Municipality of the Ashanti Region, Ghana. Anchored in constructivist theory, the research aims to: (1) examine teachers' access to EdTech resources, (2) assess the usage of EdTech in achieving Sustainable Development Goal 4 (SDG4), (3) Identify the barriers teachers face alongside the support required for effective integration. A mixed-methods research design was employed, involving a sample of 275 teachers drawn from a population of 950 using convenient sampling. Quantitative data were analyzed using descriptive statistics, percentages and standard deviation, while qualitative responses were analyzed thematically. Findings indicate that although many teachers have access to various digital tools, effective integration is hindered by limited infrastructure, inadequate training, and the absence of structured support systems. School leadership plays a crucial role in facilitating EdTech use, yet a lack of strategic planning continues to constrain meaningful implementation. The study implies that bridging these gaps is essential to ensure equitable and sustainable use of EdTech in basic education. It recommends the development of comprehensive district and school-level EdTech policies, regular professional development programmes, improved ICT infrastructure, and the establishment of teacher-led learning communities. Future research should consider comparative studies across municipalities, rurals and urbans and longitudinal evaluations to support policy and practice in advancing SDG4 through technology-enhanced education.

KEYWORDS: Educational Technology, SDG4, Basic Education, Teachers' Experiences, Constructivist Theory, ICT in Schools, Mixed-Methods Research, Ghana, Professional Development, Policy Implementation

1.0 Introduction

The global pursuit of Sustainable Development Goal 4 (SDG4) seeks to ensure inclusive, equitable, and quality education for all by 2030. Quality education, as conceptualised by UNESCO (2015), encompasses equitable access, effective teaching and learning, relevant curricula, adequate resources, and measurable learning outcomes. Yet, despite notable progress, persistent disparities in access, resources, and outcomes continue to challenge the achievement of SDG4 globally (Lee et al., 2024).

One significant barrier remains the large proportion of out-of-school children, a situation worsened by the COVID-19 pandemic, which at its peak disrupted learning for over 1.5 billion students (UNESCO, 2019; UNICEF, 2020a). Educational effectiveness—defined as the degree to which schools promote student achievement regardless of background (Ross & Mählick, 1990)—and educational efficiency—ensuring optimal use of resources to improve outcomes (Carrón & Ta Ngoc, 1980)—have become central to policy and research debates. The urgency is compounded by data showing only 4% of the poorest students complete upper secondary education compared to 36% of wealthier peers (UIS, 2017), alongside persistent inequalities linked to gender, disability, ethnicity, and conflict (UNESCO GEM, 2020; UNICEF, 2018).

Internationally, education policies are increasingly aligned with SDG4 targets. India's National Education Policy (NEP) 2020, for instance, reflects a holistic vision encompassing early childhood education (Target 4.2), technical and vocational training (Target 4.3), and teacher professional development (Target 4.c). Notably, NEP 2020 underscores the integration of educational technology (EdTech) to enhance teaching effectiveness and learning equity, resonating with Target 4.a's call to build inclusive, effective learning environments and Target 4.7's aim to advance sustainable development and global citizenship education (Kumar, 2021). This policy illustrates how strategic investment in EdTech can bridge disparities, strengthen teacher capacity, and align education systems with contemporary global demands.

Within Ghana, similar aspirations are reflected in initiatives such as the National ICT for Accelerated Development (ICT4AD) Policy and the One Teacher One Laptop programme. EdTech, defined as the systematic application of technology to facilitate learning and improve performance (AECT, 2008), includes tools like computers, mobile devices, multimedia, and internet-based resources. Research

demonstrates EdTech's potential to transform instructional practices, foster student engagement, and promote lifelong learning (Yusuf & Balogun, 2011; Volman & Van Eck, 2012).

However, a gap persists between access and effective use. Although many teachers and students in Ghanaian basic schools possess or have access to digital devices (Dzidonu, 2020), studies show limited integration into teaching and learning (Buabeng-Andoh, 2015). Factors influencing EdTech adoption include physical access, motivational readiness, digital skills, and actual classroom use (Soomro et al., 2017). Teachers' attitudes, beliefs, and confidence further shape successful implementation (Buabeng-Andoh, 2012).

In the Asante Akim Central Municipality, where this study is situated, local assessments (Sarpong et al., 2021) highlight challenges including inadequate internet connectivity, insufficient teacher training, and inconsistent technical support. Yet, effective integration of EdTech remains critical to equipping students with essential skills—critical thinking, collaboration, and digital literacy—necessary for competitiveness in the global knowledge economy (Voogt, 2012).

The primary aim of this study was to examine how teachers are using educational technology to advance Sustainable Development Goal 4 in basic schools within the Asante Akim Central Municipality in the Ashanti Region of Ghana. Grounded in these global and local contexts, this study seeks to:

1. Examine teachers' access to EdTech resources.
2. Assess the usage of EdTech in achieving Sustainable Development Goal 4 (SDG4).
3. Identify the barriers teachers face alongside the support required for effective integration.

By drawing on both Ghanaian realities and lessons from international policy innovations such as India's NEP 2020, this research aims to generate evidence-based recommendations for policymakers and educators.

2.0 Literature Review

2.1 Educational Technology Integration: Concepts, Types, and Global Perspectives

Educational technology (EdTech) refers to the systematic use of technological resources—including hardware, software, digital platforms, and networks—to enhance teaching, learning, and educational management (Selwyn, 2020). Globally, EdTech encompasses a diverse range of tools and applications, such as interactive whiteboards, mobile learning apps, Learning Management Systems (LMS), virtual labs, digital libraries, and emerging tools powered by artificial intelligence and adaptive learning (Laurillard, 2012; Almazova et al., 2021).

The integration of EdTech into classroom practice moves beyond mere access; it involves rethinking pedagogy to promote active, student-centered, and collaborative learning environments (Koehler & Mishra, 2009). Empirical studies worldwide, including those from Sub-Saharan Africa, highlight that effective integration requires alignment with curriculum, teacher professional development, and supportive institutional policies (Trucano, 2015; Nzuki, 2015).

2.2 SDG 4 and its Relevance to EdTech

Sustainable Development Goal 4 (SDG 4) aims to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" by 2030 (UNESCO, 2015). It includes seven targets addressing universal primary and secondary education, early childhood development, equal access to technical and vocational education, eliminating gender disparities, improving literacy and numeracy, and ensuring learners acquire skills for sustainable development.

EdTech has been positioned as a key enabler of SDG 4 by:

- Expanding access to underserved and remote communities (Trucano, 2015)
- Enhancing quality through adaptive and personalized learning (Selwyn, 2020)
- Fostering inclusion for learners with disabilities via assistive technologies (Alharbi & Drew, 2014)

Despite this promise, the actual impact of EdTech on SDG 4 depends on equitable deployment, teacher readiness, and culturally relevant digital content (Anamuah-Mensah, 2017).

2.3 Factors Impeding EdTech Integration

2.3.1 Infrastructural and Access Challenges

Studies in Ghana (Buabeng-Andoh, 2012; Agyei & Voogt, 2011) and broader Sub-Saharan contexts (Nzuki, 2015; Alharbi & Drew, 2014) reveal that inadequate hardware, unreliable internet connectivity, insufficient software licensing, and irregular electricity supply remain major barriers. These infrastructural deficits disproportionately affect rural and peri-urban schools, exacerbating the digital divide.

2.3.2 Teacher Capacity and Pedagogical Constraints

Effective integration hinges on teacher attitudes, digital literacy, and pedagogical skills (Koehler & Mishra, 2009). Limited professional development opportunities, high workloads, and insufficient time for lesson redesign undermine meaningful EdTech use (Selwyn, 2020). Teachers often lack training to adapt tools to local curricula and learner needs, leading to superficial use (Ginsberg & McCormack, 2018).

2.3.3 Socioeconomic and Policy-Related Challenges

Socioeconomic inequalities influence both school-level resource allocation and household access to devices and connectivity (Kwame & Mensah, 2022). In Ghana, while policies like the ICT for Accelerated Development (ICT4AD) exist, empirical evaluations reveal limited translation into classroom-level practice (Ministry of Education, 2019). Gender disparities and language barriers further compound exclusion (Anamuah-Mensah, 2017).

2.4 Empirical Studies: Ghana and Sub-Saharan Africa

Table 1: summarizes selected findings of empirical research highlights similar challenges across contexts.

Study	Context	Focus	Key Findings
Buabeng-Andoh (2012)	Ghana	Teacher ICT use	Inadequate training; low confidence
Agyei & Voogt (2011)	Ghana	Curriculum integration	Need for context-relevant training
Nzuki (2015)	Kenya	Rural schools	Infrastructure gaps; policy-practice gap
Alharbi & Drew (2014)	Nigeria	Secondary schools	Socioeconomic barriers; limited support
Kwame & Mensah (2022)	Ghana	Equity and access	Gender and regional disparities

While common patterns emerge, Ghanaian studies are limited by small samples, urban focus, and cross-sectional designs. Few track long-term outcomes or explore the interplay of policy, teacher agency, and local culture.

2.5 Theoretical Framework

This study adopts constructivist theory (Volman, 2012), which posits that learners and teachers co-construct knowledge through interaction with content, peers, and technology. In the EdTech context, constructivism supports active learning, critical thinking, and personalized pathways—aligning closely with SDG 4’s targets for inclusive and equitable quality education.

Widely used models like TAM (Davis, 1989) and UTAUT (Venkatesh et al., 2003) offer insights into technology acceptance but primarily address higher education and corporate contexts. Their applicability to resource-constrained Ghanaian basic schools is limited (Agyeman, 2020). This study instead focuses on how teachers’ professional identities, pedagogical choices, and contextual realities shape EdTech use.

2.6 Conceptual Framework

Building on constructivism, the conceptual framework (Figure 1) positions EdTech Usage at the center, linking it to four domains:

- Teachers' EdTech Accessibility: Skills, motivation, and digital resources.
- Structural Adaptation: Curriculum alignment, classroom redesign, and infrastructure.
- Leadership Structure: Vision, policies, and administrative support.
- Support System: Ongoing professional development and technical assistance.

These domains collectively influence three core outcomes: Cost Effectiveness, Enhanced Educational Accessibility, and ultimately Quality Education (SDG 4).

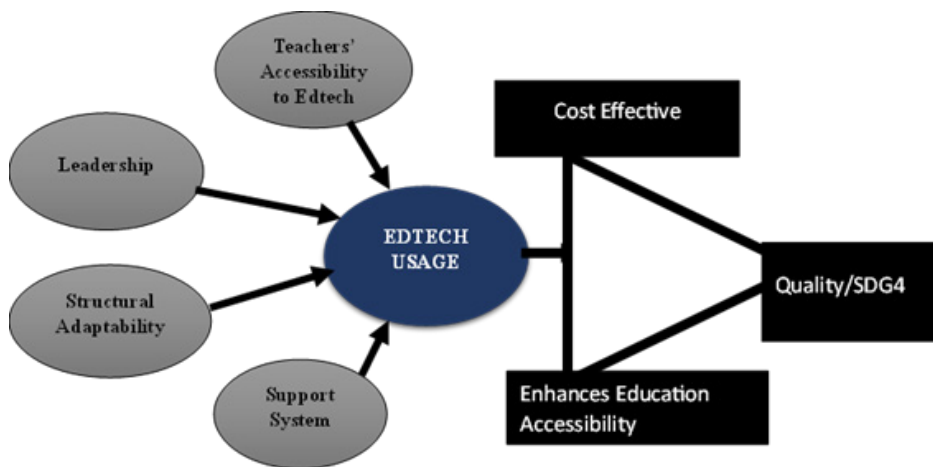


Figure 1. Conceptual Framework: Interplay of factors shaping EdTech integration to achieve SDG 4 in Asante Akim Central Basic Schools

Source: Author's Construct

3.0 Research Methodology

This study adopted a pragmatic and rigorous methodological approach to explore teachers' experiences with educational technology (EdTech) integration for achieving SDG4 in Asante Akim Central Municipality. The methodology aligns with the research aim by combining quantitative and qualitative strands, supported by a sequential explanatory mixed-methods design.

3.1 Research Philosophy

The study was guided by the pragmatist paradigm, which emphasizes practical solutions to research questions rather than strict adherence to epistemological or ontological positions (Teddle & Tashakkori, 2018). This allowed integration of quantitative and qualitative approaches to develop a comprehensive understanding of EdTech adoption among teachers. Pragmatism supports methodological pluralism, valuing data and insights that best address the research questions, as advocated by Creswell (2018).

3.2 Research Design and Approach

The study followed a sequential explanatory design (Creswell, 2018), where quantitative data were collected and analyzed first, followed by qualitative data to interpret and deepen understanding of the quantitative results. The quantitative phase provided broad statistical patterns, while the qualitative phase explored contextual factors and personal experiences. The integration of findings occurred during interpretation, allowing for triangulation to strengthen validity and comprehensiveness (Tashakkori & Teddle, 2010).

3.3 Research Area

The research focused on public basic schools in Asante Akim Central Municipality, located in the Ashanti Region of Ghana. This area was selected based on the diversity of its urban and rural schools and ongoing educational initiatives that directly relate to SDG4 (Addai, 2024; Humphrey-Darkeh et al., 2022). The mix of contexts provided a meaningful backdrop for studying EdTech access and integration.

3.4 Population

The target population comprised all public basic school teachers in the municipality. The accessible population of 950 teachers was determined using the official staff lists obtained from the Municipal Education Directorate. This number reflects all full-time teaching staff at kindergarten, primary, and junior high school levels within the public education system.

3.5 Sample Size and Sampling Technique

The required sample size was determined using Krejcie and Morgan's (1970) formula: $n = \frac{N}{1 + (N-1)e^2}$ where $N = 950$ and $e = 0.05$. This calculation produced a sample size of approximately 274, which was rounded to 275 to enhance representativeness. The result aligns with the Krejcie and Morgan table for a 95% confidence level.

A convenience sampling technique (Etikan et al., 2016) was used for the quantitative phase due to practical considerations such as time constraints, accessibility, and willingness of teachers to participate. The authors acknowledge that convenience sampling may introduce sampling bias, potentially overrepresenting teachers with better digital connectivity or greater interest in EdTech. Future research should consider stratified random sampling to ensure proportional representation across different school settings and teacher categories, thereby enhancing generalizability.

For the qualitative phase, purposive sampling (Palinkas et al., 2015) selected six participants: two computing teachers, two headteachers, and two School Improvement Support Officers (SISOs). This approach ensured collection of rich, context-specific data from individuals directly involved in EdTech adoption and policy implementation.

3.6 Data Collection Instruments

Data collection combined a self-administered questionnaire and structured interviews. The questionnaire was adapted from the validated Faculty's Information and Communication Technology Access (FICTA) scale developed by Soomro et al. (2017), which covers physical, motivational, skills, and usage access. In this study, "ICT" was replaced with "EdTech" to reflect the specific focus. The structured interviews explored participants' experiences, perceptions, and challenges regarding EdTech integration.

3.7 Validity and Reliability

The FICTA scale has established validity and reliability, including content validity, discriminant validity, and Principal Component Analysis (Soomro et al., 2017). Reported reliability coefficients for subscales ranged from $\alpha = .780$ to $\alpha = .885$, indicating strong internal consistency. The adaptation to EdTech terminology maintained the original instrument's structure and psychometric properties.

3.8 Data Collection Procedure

Permission to collect data was secured from the Ghana Education Service via the Municipal Education Office. The questionnaire was distributed online using Google Forms, supplemented by in-person support for teachers with limited digital access. Interviews were conducted face-to-face and audio recorded with consent. Participant anonymity and data confidentiality were assured throughout the process.

3.9 Instrument Scoring

Responses on Likert-scale items were scored as follows: Strongly Agree = 1, Agree = 2, Disagree = 3, Strongly Disagree = 4. Lower scores indicated stronger agreement or higher access.

3.10 Data Analysis

Quantitative data were analyzed using SPSS (version 23) and Excel, producing descriptive statistics including frequencies and percentages. Qualitative data were analyzed thematically (Braun & Clarke, 2020), identifying recurrent themes and patterns that contextualized and explained the quantitative findings.

3.11 Ethical Considerations

Ethical clearance was granted by the Humanities and Social Sciences Ethics Committee, Kwame Nkrumah University of Science and Technology (KNUST). Written informed consent was obtained from all participants, emphasizing voluntariness, confidentiality, and the right to withdraw at any time. Anonymity was ensured by coding schools and participants, and data were securely stored.

This study used a sequential explanatory mixed-methods design grounded in a pragmatic philosophy. It integrated quantitative breadth with qualitative depth to explore EdTech integration in the context of SDG4. Recognizing the limitations of convenience sampling, the study recommends more representative sampling techniques in future research to enhance generalizability.

4.0 Findings and Discussion

This section presents and discusses the results of the study based on data gathered from basic school teachers in Asante Akim Central Municipality. It is organized into two phases: the first presents quantitative data (using descriptive statistics), and the second discusses qualitative findings. The chapter concludes with a discussion that integrates the two strands of data in relation to the research objectives and existing literature.

4.1 Demographic Profile of Respondents

Understanding respondents' demographic characteristics provides insight into how variables such as age, teaching experience, and position may influence Ed-Tech use.

Table 2: Age Range of Respondents

Age Group	Frequency	Percent
20–30 years	105	38.2%
31–40 years	128	46.5%
41–50 years	27	9.8%
51–60 years	15	5.5%
Total	275	100%

(Source: Field Data, 2023)

The majority of respondents (46.5%) were aged 31–40 years, aligning with findings by Akinde and Adetimirin (2017) that younger teachers dominate the teaching profession in basic schools.

Table 3: Teaching Experience

Experience	Frequency	Percent
0–5 years	108	39.3%
6–10 years	59	22.6%
11–15 years	55	20.0%
16–20 years	18	6.5%
21–25 years	18	6.5%
25+ years	14	5.1%
Total	275	100%

(Source: Field Data, 2023)

Most teachers had between 0–5 years of experience (39.3%), suggesting a relatively young and emerging workforce.

Table 4: Teaching Position

Position	Frequency	Percent
Classroom Teacher	99	36.0%
Subject Teacher	124	45.1%
Headteacher	35	12.7%
Office Worker	17	6.2%
Total	275	100%

(Source: Field Data, 2023)

Subject teachers made up the majority, followed by classroom teachers and head-teachers.

Table 5: Teaching Level

Level	Frequency	Percent
Education Office	20	7.3%
Junior High School	128	46.5%
Kindergarten	28	10.2%
Lower Primary	42	15.3%
Upper Primary	57	20.7%
Total	275	100%

(Source: Field Data, 2023)

Junior High School teachers formed the largest group (46.5%), which may affect the types of EdTech tools needed and used.

4.2 Quantitative Data Analysis

Table 6: Access to EdTech Tools

Tool	Yes N (%)	No N (%)
Laptop	191 (69.5%)	83 (30.2%)
Smartphone/Tablet/iPad	259 (94.2%)	16 (5.8%)
USB Flash Drive	191 (69.5%)	79 (28.7%)
Office Software Suite	193 (70.2%)	82 (29.8%)
Broadband Internet	96 (34.9%)	172 (62.5%)
LMS	134 (48.7%)	140 (50.9%)
Printer	56 (20.4%)	219 (79.6%)
219 (79.6%)	48 (17.5%)	223 (81.1%)
Desktop Computer	95 (34.5%)	176 (64.5%)

Photo Editing Software	94 (34.2%)	179 (65.1%)
Video Editing Software	62 (22.2%)	213 (77.8%)

(Source: Field Data, 2023)

Most teachers had access to basic tools such as smartphones (94.2%) and laptops (69.5%). However, access to internet connectivity, printers, and specialized software was limited. This supports earlier findings by Eze et al. (2018) and Atuahene (2021) that basic school teachers face significant EdTech access challenges

Table 7: Teachers’ Motivation to Use EdTech

Statement	Mean	SD
EdTech makes teaching easier and enjoyable	3.8	0.9
Motivated by students' enthusiasm when using EdTech	3.7	1.0
Motivated by school support for EdTech	2.9	1.1
Motivated by access to training and workshops	2.7	1.2

(Source: Field Data, 2023)

Teachers felt intrinsically motivated to use EdTech when it made teaching enjoyable or improved student engagement. However, external motivation such as institutional support and training was weak—highlighting a gap in professional development initiatives.

Table 8: Teachers’ Proficiency in EdTech

Tool/Skill	Proficient N (%)
Word Processing	235 (85.5%)
Internet Browsing	207 (75.3%)
Presentation Tools (e.g., PPT)	155 (56.4%)
Spreadsheet	123 (44.7%)
LMS Use	102 (37.1%)
Video Conferencing Tools	94 (34.2%)
Multimedia Creation Tools	61 (22.2%)
Data Analysis Tools	48 (17.5%)

(Source: Field Data, 2023)

Teachers demonstrated high proficiency in basic tools but limited skills in LMS, data analysis, and multimedia tools. This proficiency gap aligns with Atuahene (2021) and suggests the need for targeted training.

Table 9: Key Challenges Reported

Challenge	Frequency	Percent
Lack of infrastructure	219	79.6%
Limited or no internet connection	172	62.5%
No in-service training	190	69.1%
High cost of devices	146	53.1%
Lack of technical support	138	50.2%

(Source: Field Data, 2023)

Infrastructure and training remain the most critical barriers to effective EdTech integration. These findings align with Ofosu-Appiah (2017) and Paul & Chandak (2019), who observed similar constraints in developing contexts.

4.3 Qualitative Data Analysis

This section presents qualitative findings that enrich the quantitative results by exploring teachers’ engagement with educational technology (EdTech) in basic schools to advance Sustainable Development Goal 4 (SDG4). Thematic analysis, based on Braun and Clarke (2020), was used for its flexibility in analyzing interview data and identifying patterns related to EdTech adoption in Asante Akim Central.

Semi-structured interviews were conducted with six purposefully selected participants—two headteachers, two ICT teachers, and two School Improvement Support Officers (SISOs). The interviews explored EdTech engagement, challenges, and needed support. Ethical procedures were followed, including informed consent and anonymization (Cheng, Taylor, & Tong, 2016). Prior to the interviews, participants were provided with detailed information about the study’s objectives, their rights, and the consent process (Cheng, Taylor, & Tong, 2016). To ensure participant anonymity, personal identifiers were replaced with pseudonyms and numerical codes (Cheng, Taylor, & Tong, 2016).

Interview transcripts were analyzed through the phases of thematic analysis (Braun & Clarke, 2013), leading to the identification of three key themes:

- Access to EdTech Resources
- Challenges in Utilization
- Motivation and Support for Integration

Theme 1: Accessibility to EdTech Resources

Participants consistently emphasized that access to EdTech resources remained limited and uneven across schools.

“Our teachers face significant challenges in accessing computers, both physically and in terms of acquiring the necessary skills within the school premises.”

— Mr. Kwame, ICT Teacher

“There are considerable difficulties for our teachers when it comes to accessing computers and obtaining the essential skills to use them effectively within the school environment.”

— Ms. Afriyie, ICT Teacher

“We recognize the importance of EdTech, but limited access to computers and internet infrastructure remains a barrier.”

— Mr. Boateng, Headteacher

“Our school struggles with inconsistent access to ICT resources, impacting our ability to fully integrate technology into teaching.”

— Ms. Osei, Headteacher

“The variability in ICT infrastructure and resources across schools poses challenges for effective EdTech implementation.”

— Mr. Mensah, SISO

“There's a clear need for improved investment in ICT infrastructure to support teachers in meeting SDG4 targets.”

— Ms. Agyeman, SISO

Theme 2: Challenges in Utilizing EdTech

The interviews exposed a gap between awareness of EdTech and the ability to use it effectively. While quantitative findings indicated a positive attitude towards EdTech, qualitative data revealed deep-seated structural and skill-related barriers. While teachers recognized EdTech's value, skill gaps and structural barriers hindered effective use:

"Many teachers still lack confidence to use even basic tools beyond Word or PowerPoint." —Mr. Kuma, SISO

"Without regular training, it's difficult for teachers to keep up with new tools." —Ms. Lena, ICT Teacher

Participants noted that many teachers lacked the training needed to navigate educational technologies confidently. Schools also faced logistical challenges such as unstable electricity supply and outdated equipment, which discouraged consistent EdTech use.

Theme 3: Motivation and Support for EdTech Integration

Despite these challenges, educators expressed motivation to integrate EdTech, emphasizing its potential to transform learning outcomes and enhance inclusivity.

"EdTech plays a crucial role in transforming learning outcomes and fostering critical skills aligned with SDG4."

— Mr. Kwame, ICT Teacher (Zaman, Shamin, & Clement, 2011, p. 5)

"We advocate for EdTech to enhance inclusive education and active learning, supporting the goals of SDG4."

— Ms. Afriyie, ICT Teacher (Rehn, 2016, p. 72)

"EdTech enables personalized learning and inclusive education, crucial for achieving SDG4 objectives."

— Mr. Boateng, Headteacher

"It expands access to education, particularly in underserved areas, and equips students with 21st-century skills necessary for their future."

— Ms. Osei, Headteacher (Ota, 1995, p. 112)

Participants advocated for continuous professional development and strategic support to enable educators to leverage EdTech tools meaningfully. The desire to bridge the digital divide and improve learner outcomes was evident across the interviews.

Participants advocated for continuous professional development and strategic support to enable educators to leverage EdTech tools meaningfully. The desire to bridge the digital divide and improve learner outcomes was evident across the interviews.

4.4 Discussion

This study explored the integration of Educational Technology (EdTech) in basic schools within the Asante Akim Central Municipality in relation to Sustainable Development Goal 4 (SDG4). The findings indicate that teachers' proficiency with EdTech significantly influences usage patterns, reaffirming that digital skills are critical for effective integration (Tan, 2020; Tan, 2023). The positive relationship between skill levels and utilization supports existing literature advocating for targeted, continuous professional development.

Challenges identified include limited ICT infrastructure, inadequate access to devices and connectivity, and the absence of fully equipped ICT laboratories. These constraints are consistent with prior research highlighting foundational barriers to EdTech adoption in low-resource settings (Daniel, 2010; Chua, 2012). Additionally, training inconsistencies and the lack of tailored support—especially for older or less technologically experienced teachers—impede progress. Although professional development initiatives exist, they are often infrequent and misaligned with the practical needs of educators (Daniel, 2010).

The findings further indicated gaps in EdTech policy, minimal curriculum coverage, and insufficient incentives for teachers. The absence of structured motivation mechanisms contributes to underutilization of available tools. SISOs emphasized the need for strategic coordination, policy coherence, and structural alignment across educational actors to support implementation. These findings align with existing literature underscoring the importance of leadership, institutional support, and systemic reform in facilitating EdTech integration (Fullan, 2012, 2022; Soomro et al., 2017; Yildirim, 2007).

5.0 Conclusion and Recommendations

The study investigated teachers' access to educational technology (EdTech) as a means to achieve Sustainable Development Goal 4 (SDG4) in Asante Akim Central Municipality. The results indicated that while some basic forms of EdTech are available to teachers, access remains inconsistent and largely inadequate for promoting inclusive and quality education. Internet connectivity, up-to-date digital tools, and sustained support for professional development are still lacking.

It was also observed that teachers' access varied by school location, with rural and public schools facing greater challenges. This suggests the need for targeted interventions. The study's findings highlight that achieving SDG4 through EdTech requires not only infrastructure but also teacher empowerment, contextual sensitivity, and policy coherence.

A key implication is that access alone is insufficient; meaningful integration of EdTech depends on teacher readiness, digital literacy, and institutional support. One limitation of the study was its focus on quantitative data, which may not fully capture the nuances of teacher experiences. Additionally, generalizability may be limited due to the study's municipal focus. In conclusion, bridging the digital divide and empowering educators with relevant tools and training will be crucial for Ghana's efforts to achieve SDG4, especially in marginalized communities.

Based on the findings of this study, several recommendations are proposed. Firstly, it is essential for educational policymakers and local authorities to invest in the equitable provision of educational technology (EdTech) infrastructure, particularly in underserved areas such as Asante Akim Central. The digital divide continues to be a major barrier to achieving inclusive and equitable quality education as outlined in SDG4 (UNESCO, 2021). Provision of reliable internet connectivity, devices, and digital tools for both teachers and learners should be prioritized.

Secondly, the Ghana Education Service (GES) should integrate mandatory digital literacy and EdTech training into both pre-service and in-service teacher development programs. This aligns with the view that teachers' professional development is key to effective EdTech integration (Tondeur et al., 2017). Continuous professional development should also include training on digital pedagogy, online assessment methods, and the use of open educational resources (OERs).

Finally, future studies should consider employing mixed-method designs to better understand both the measurable levels of EdTech access and the contextual factors that shape their use. The combination of quantitative data and qualitative insights will enrich the understanding and help refine policies tailored to specific educational contexts (Creswell & Plano Clark, 2018).

6.0 Acknowledgement

I would like to appreciate the immense contribution of Dr. Samuel Antwi, my supervisor, for his professional guidance and advice in this research work. I cannot thank him enough so I wish God's blessings for him.

References

- Agyekum, B. O., Osei-Poku, P., & Osei-Tutu, E. (2022). The integration of educational technologies in basic schools in Ghana: Challenges and opportunities. *Journal of Educational Technology and Development Studies*, 14(1), 45–59.
- Alhassan, R., & Ali, Z. (2020). Challenges and prospects of ICT integration in West African secondary schools. *International Journal of Education and Development using ICT*, 16(2), 1–13.
- Ally, M. (2008). Foundations of educational theory for online learning. In T. Anderson (Ed.), *The theory and practice of online learning* (2nd ed., pp. 15–44). Athabasca University Press.
- Amankwah, F., Yeboah, R., & Koomson, C. K. (2021). Integrating ICT in basic education in Ghana: Teachers' practices and challenges. *International Journal of Educational Development*, 84, 102–115.
- Atuahene, F. (2021). Digital inclusion in Ghanaian basic schools: Opportunities and challenges. *Journal of Educational Technology in Africa*, 9(2), 45–58.
- Bhateja, V., Soomro, K. A., & Ahmad, R. (2018). Investigating access dimensions of ICT usage in faculty: A study using FICTA scale. *Journal of Educational Computing Research*, 56(8), 1203–1221.

- Braun, V., & Clarke, V. (2013). *Successful qualitative research: A practical guide for beginners*. SAGE Publications.
- Braun, V., & Clarke, V. (2020). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology*, 18(3), 328–352. <https://doi.org/10.1080/14780887.2020.1769238>
- Bryman, A. (2016). *Social research methods* (5th ed.). Oxford University Press.
- Buabeng-Andoh, C. (2012). Factors influencing teachers' adoption and integration of ICT into teaching: A review of the literature. *International Journal of Education and Development using ICT*, 8(1), 136–155.
- Cheng, M., Taylor, R., & Tong, E. (2016). Ethical issues in educational research. *Journal of Research Ethics*, 12(3), 201–212.
- Chua, S. L. (2012). ICT integration in primary schools: Barriers and enablers. *Malaysian Online Journal of Educational Technology*, 2(3), 20–30.
- Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Sage Publications.
- Daniel, J. (2010). ICTs in education: A framework for development. *Commonwealth of Learning*.
- Dube, B. (2019). Rural teachers' experiences of digital learning: Challenges and implications. *African Education Review*, 16(4), 19–34.
- Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*,

5(1), 1–4.

Eze, S. C., Chinedu-Eze, V. C., & Bello, A. O. (2018). The utilisation of e-learning facilities in primary schools in sub-Saharan Africa. *Educational Technology & Society*, 21(2), 70–82.

Fullan, M. (2012). *Stratosphere: Integrating technology, pedagogy, and change knowledge*. Pearson.

Fullan, M. (2022). *The new meaning of educational change* (5th ed.). Teachers College Press.

Hennessy, S., Harrison, D., & Wamakote, L. (2010). Teacher factors influencing classroom use of ICT in Sub-Saharan Africa. *Itupale Online Journal of African Studies*, 2(1), 39–54.

Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2006). Using mixed-methods sequential explanatory design: From theory to practice. *Field Methods*, 18(1), 3–20.

Karsenti, T., Collin, S., & Harper-Merrett, T. (2019). Pedagogical integration of ICT: Successes and challenges from 100+ classrooms in Finland. *European Journal of Education Studies*, 6(3), 93–112.

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, 30, 607–610.

Lee, Y., Tan, S. C., & Goh, W. S. (2014). The next generation of e-learning: Strategies for engagement and instruction. *Educational Media International*, 51(1), 3–17.

Ministry of Education. (2015). *ICT in Education Policy*. Accra: Government of Ghana.

Ng, W. (2020). Using digital technology in Singaporean schools: Leadership for innovation and teacher professionalism. *International Journal of Educational Management*, 34(1), 2–15.

Ofori-Appiah, K. (2017). Challenges of ICT integration in Ghanaian schools. *African*

Journal of Educational Studies, 5(1), 35–49.

Ota, C. (1995). Teaching with technology: Tools for today's learners. *Educational Media International*, 32(2), 110–115.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, 42(5), 533–544.

Patton, M. Q. (2014). *Qualitative research and evaluation methods* (4th ed.). SAGE Publications.

Paul, T., & Chandak, A. (2019). Infrastructure and ICT usage in rural education. *International Journal of Education and Development using ICT*, 15(3), 12–25.

Rehn, N. (2016). Inclusive education through technology in African contexts. *Tech &*

Ed Review, 14(1), 65–75.

Riggs, I. M., & Enochs, L. G. (2014). Toward the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education*, 74(6), 625–637.

Selwyn, N. (2012). *Education and technology: Key issues and debates*. Bloomsbury Publishing.

Sekaran, U. (2018). *Research methods for business: A skill-building approach* (7th ed.).

Wiley.

Soomro, K. A., Ahmad, R., & Bhatti, Z. A. (2017). Faculty's ICT access and use: A scale validation study. *The International Review of Research in Open and Distributed Learning*, 18(4), 88–104.

Soomro, K. A., Bhatti, Z. A., & Ahmad, R. (2020). Measuring ICT access dimensions among university faculty: Validating the FICTA scale. *Education and Information Technologies*, 25, 3239–3258.

- Soomro, S., Zai, S. Y., & Jafri, A. (2017). Role of school leadership in technology integration: A case from Pakistan. *Journal of Educational Leadership*, 9(1), 101–119.
- Tan, C. (2020). Digital skills and e-learning readiness among teachers. *Journal of Online Learning Research*, 6(4), 315–330.
- Tan, C. (2023). Integrating EdTech into school curricula: Skill, policy, and pedagogical factors. *Journal of Contemporary Education*, 11(1), 15–27.
- Teddlie, C., & Tashakkori, A. (2009). Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences. SAGE Publications.
- Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2017). A comprehensive analysis of TPACK within preservice teachers' ICT profiles: Mind the gap! *Journal of Educational Technology & Society*, 20(3), 134–150.
- Tondeur, J., Van Braak, J., Ertmer, P. A., & Ottenbreit-Leftwich, A. (2017). Understanding the relationship between teachers' pedagogical beliefs and technology use in education. *Computers & Education*, 108, 1–13.
- UNESCO. (2021). Digital learning and transformation of education systems: A framework for action. Paris: UNESCO.
- UNESCO. (2021). Reimagining our futures together: A new social contract for education. UNESCO Publishing.
- UNESCO. (2023). Technology in education: A tool on whose terms? Paris: UNESCO.
- Van Dijk, J. (2005). The deepening divide: Inequality in the information society. SAGE Publications.
- Volman, M. (2012). Teachers and technology: Conditions for effective use of ICT in teaching. *Teacher and Teacher Education*, 28(1), 19–27.
- Yildirim, S. (2007). Current utilization of ICT in Turkish basic education schools: A

review of teacher's ICT integration. *International Journal of Instructional Technology and Distance Learning*, 4(1), 17–32.

Zaman, M., Shamin, R., & Clement, P. (2011). ICTs for achieving MDGs and SDGs in education: The case of Bangladesh. *UNESCO Global Education Review*, 3(1), 1–10.

Emerging Trends In Inclusive And Accessible Digital Education In Zimbabwe: A Forward-Thinking Framework For Equity And Innovation

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ABSTRACT:

Students with disabilities and members of marginalized communities still confront major obstacles to inclusion and access, even in the face of the swift adoption of digital technologies in African education. In Zimbabwe, educational inequality is made worse by the digital divide, which still exists in rural and underdeveloped areas. With an emphasis on Zimbabwean educational systems, this study intends to investigate new pedagogical and technological developments that improve accessibility and inclusivity in online learning environments. Using a mixed-methods approach, this study examines Zimbabwe's accessibility-focused digital platforms, conducts interviews with educators and officials, and analyzes case studies. Additionally, it incorporates ideas from international best practices and inclusive education frameworks that have been modified for the Zimbabwean environment. Three significant breakthroughs surfaced: 1) AI integration for personalized learning in real time; 2) Working with students with disabilities to co-create accessible curriculum; and 3) The application of accessible immersive technology. Additionally, there is a noticeable change from accessibility that is focused on compliance to proactive, anticipatory design paradigms. Policymakers, educational technologists, and organizations working to bridge the digital divide can all benefit from the study's practical lessons. It illustrates how cross-sector cooperation, ethical design, and local creativity can enhance educational equity in Zimbabwe and comparable settings. When used responsibly and locally, emerging technologies have the potential to revolutionize inclusive education in Zimbabwe. To guarantee that every student succeeds in a digitally enabled setting, accessibility must be ingrained from the beginning.

KEYWORDS: Inclusive education, digital accessibility, Zimbabwe, Universal Design for Learning, assistive technologies, educational equity

1. Introduction

Inclusive education is the provision of quality schooling that embraces all learners, especially those with disabilities and is a human right and global imperative (SDG 4). In Zimbabwe, recent policy advances such as the Education Amendment Act (2020) and recognition of sign language have laid a foundation for inclusion, but substantial gaps remain. Only about 10% of Zimbabwean children with disabilities are enrolled in school, and even fewer have equal access to emerging digital tools. At the same time, the COVID-19 pandemic and rapid digital transformation highlighted a digital divide: according to UNESCO and ITU data, merely 16% of households in developing countries had Internet versus 66% in developed countries and only 26% of Africans were online in 2021. Connectivity in sub-Saharan Africa remains low, 44% of people had mobile phones and only 27% had mobile Internet in 2023, largely due to high device costs (a smart phone can cost up to 95% of a poor household's monthly income), limited content in local languages, and unreliable electricity (only 43% of Africans have constant power). These barriers disproportionately affect rural and marginalized communities in Zimbabwe, compounding educational inequities.

Given this context, there is an urgent need to explore how digital accessibility can advance Zimbabwe's inclusive education goals. The knowledge gap lies in understanding which technological and pedagogical innovations can bridge the digital divide for students with disabilities here. While global studies highlight the potential of educational technology and universal design to transform learning, there is little research on how these ideas apply to Zimbabwe's schools and learners.

1.1 Aim and Objectives:

This study aims to investigate strategies for improving digital accessibility in Zimbabwean education for students with disabilities and other marginalized groups. Specifically, the objectives are:

- To identify current barriers to digital learning and inclusion in Zimbabwean schools through qualitative inquiry
- To audit commonly-used educational technology platforms for accessibility compliance
- To document case studies of promising inclusive-education initiatives
- To propose innovative, anticipatory design solutions – including AI-driven personalization, co-created curricula, and immersive technologies – that can make learning more inclusive.

1.2 Contributions and Beneficiaries

This research will fill a gap in knowledge about digital inclusion in Zimbabwe's education sector. Academically, it links theories of Universal Design for Learning (UDL) and the digital divide with on-the-ground evidence. Practically, the findings will benefit policymakers (e.g. Ministry of Education, disability committees), educators, and EdTech developers by identifying priority interventions. Importantly, it centers the voices of students with disabilities and marginalized groups as co-creators of solutions. Ultimately, the intended beneficiaries are the learners themselves: by informing more inclusive policy, technology, and teaching practices, the study aims to empower students with disabilities to access high-quality learning alongside their peers.

2. Literature Review

2.1 Digital Divide in Sub-Saharan Africa

Across Sub-Saharan Africa (SSA), large segments of the population remain offline. Only 27% of people had mobile Internet in 2023, and even fewer had broadband, (GSMA, 2023). Affordability is a key barrier: smart phones and data are prohibitively expensive for low-income families. In rural areas, lack of electricity (just 43% grid access) further limits ICT use.

Research on Zimbabwe's distance-learning sector highlights enduring challenges faced by both students and educators, such as inadequate infrastructure, high internet data costs, and frequent power outages. For example, Kurebwa, Moyo, & Lumbe(2025) report that Zimbabwean learners encountered network failures and no device access, which "deepen the divide" in educational opportunity. In response, initiatives like UNICEF's Learning Passport have provided offline digital hubs loaded with Zimbabwean curriculum content, enabling remote schools to use digital lessons without Internet. This illustrates one approach to mitigating the connectivity gap: bringing the platform to the learner, rather than expecting ubiquitous connectivity.

2.2 Inclusive Education Concepts

Inclusive education means designing the system so all learners regardless of ability, gender, or background can participate fully. This principle is enshrined in international commitments (e.g. Salamanca Statement, CRPD) and in Zimbabwe's laws (Education Act revisions). In practice, however, children with disabilities are still disadvantaged in SSA. UNESCO and World Bank analyses show that children with disabilities are about 10 to 13 percentage points less likely to complete primary schooling than their peers, and these gaps widen at higher levels, (Wodon,

2017). A UNESCO report notes that Zimbabwe, for example, has the distinction of being one of the few African countries to recognize sign language officially and attempt inclusive policies, but still struggles with infrastructure and teacher training. In-country surveys confirm that only about half of schools in Zimbabwe are equipped to welcome learners with disabilities. Against this backdrop, the rationale for inclusive design is to go beyond mere compliance: inclusive education should “invariably benefit people living with disabilities first” because they are most marginalized. A user-centered shift in pedagogy (not just retrofitting ramps and text-to-speech) is advocated, following models like Universal Design for Learning (UDL). UDL offers a framework of multiple means of engagement, representation and expression so that curricula are intrinsically accessible to diverse learners. UNESCO’s 2020 Global Education Monitoring report explicitly recommends integrating UDL at the policy level for inclusive education. In low-resource settings, UDL’s emphasis on flexible teaching methods can potentially be adapted (with appropriate local innovations) to support learners who have historically been left behind.

2.3 Assistive and Accessible Technologies

Technology can play a critical role in inclusive education by providing alternate ways to access content. For example, assistive devices such as screen readers, braille displays, and hearing aids help students overcome sensory and mobility barriers. As UNESCO notes, “assistive devices help persons with disabilities overcome major barriers” to full participation. More recently, mainstream digital tools (smartphones, tablets, laptops) have become valuable platforms for inclusion. Accessible technologies those designed for general use but beneficial for disabled users often have advantages of low cost and low stigma, (Vanderheiden, 2011). Research shows that many visually impaired users now prefer common devices (e.g. mobile apps with voice control) over specialized gadgets (Lazar, Goldstein, & Taylor, 2015). Moreover, technology enables content to be presented in multiple ways: a single lesson can include text, audio narration, video captions, or interactive elements, thereby catering to different needs. Systematic reviews find that mobile devices, AR/VR applications, and interactive software can make learning more inclusive by removing barriers. For instance, augmented reality can provide spatial audio or enlarged text, while AI-driven captioning can transcribe lectures in real time. However, the literature also warns that technology alone is not enough. Many digital learning platforms lack built-in accessibility features (e.g. no sign-language interpretation or poor contrast), and teachers often lack training to use technology inclusively. COVID-19 lockdowns illustrated this vividly: without design for disabilities, remote learning often excluded learners who need accommodations. Thus, as multiple authors emphasize, accessibility must be a design priority, not an afterthought.

2.4 Assistive Technology in Africa

Across sub-Saharan Africa, the availability of assistive technology is limited by cost and infrastructure. International organizations highlight programs delivering devices (e.g. wheelchairs, braille readers) to African schools as life-changing. In Zimbabwe specifically, UNICEF reports that dozens of schools now use braille typewriters and screen-reading software to help visually impaired students. Partnerships funded by Global Partnership for Education have supplied over 77,000 children with devices covering visual, hearing and mobility impairments, (UNICEF Zimbabwe, 2024). These interventions underscore that assistive tech, combined with trained specialist teachers, can dramatically improve participation. At the same time, projects like UNESCO's ITE are piloting AI tools (e.g. speech-to-text, text-to-speech, sign-language translation, adaptive learning platforms) in African contexts. Zimbabwean stakeholders have expressed optimism that AI could break information barriers for persons with disabilities. This suggests a convergence of global innovation (AI, UDL, immersive tech) with local commitment, offering new possibilities if adapted thoughtfully to the local context.

2.5 Life-Changing Interventions

Despite these constraints, international agencies report life-changing AT programs in African schools. For example, UNICEF highlighted a program in Rwanda that delivered hearing aids to children with deafness; "hundreds of children can now hear their teacher at school," restoring their ability to participate in class (UNICEF, 2022). In Somalia, a Save the Children/GPE project provided students with visual impairments magnifiers, hearing aids and other devices. One 17 year old girl called her new electronic magnifier "like a magic wand," saying, "a whole new world has opened up for me". These stories illustrate how wheelchairs, Braille tools and similar devices can dramatically improve inclusion and learning outcomes.

2.6 Emerging AI-driven Approaches

Meanwhile, new AI and immersive technologies are being piloted in African education. UNESCO (2025), reports that in 2024 it organized an AI hackathon in Kenya to develop assistive-tech solutions for special-needs education. These include AI tools such as speech-to-text, text-to-speech and sign-language translation to help learners with disabilities. Zimbabwean stakeholders have welcomed such innovations: for instance, a national disability leader recently remarked that technology "had the potential to break the barriers to information" for persons with disabilities (Sunday Mail, 2024). Taken together, these examples suggest a convergence of global innovation (AI, Universal Design, AR/VR, etc.) with local commitment, opening new possibilities for inclusion if adapted thoughtfully to the Zimbabwean context.

In summary, the literature indicates an urgent need to blend inclusive pedagogy (UDL, assistive tools, co-created learning) with initiatives to close the digital gap. Building on past work, our study will explore how these principles can be implemented in Zimbabwe's education system.

3. Research Methodology

3.1 Overview

We employed a mixed-methods design to capture both depth and breadth of the inclusive-technology landscape. This approach combines qualitative inquiry with evaluative auditing and illustrative case studies to answer our research questions comprehensively.

3.2 Qualitative Interviews

We conducted semi-structured interviews with three groups of stakeholders: (a) teachers and school administrators in urban and rural settings; (b) students with disabilities (and their parents/caregivers); and (c) education specialists and disability advocates (including government and NGO representatives). Purposive sampling ensured inclusion of various impairments (visual, hearing, mobility, cognitive) and contexts. Interview questions addressed experiences with technology in schooling, perceived barriers (e.g. device access, literacy), and ideas for improvement. Data were analyzed using thematic coding: transcripts were reviewed for key themes (e.g. "access challenges," "adaptive teaching methods," "success stories") to identify common patterns and divergent perspectives. This qualitative strand provides rich contextual insight into lived challenges and needs.

3.3 Platform Accessibility Audits

To assess the digital environment, we selected several widely-used educational platforms in Zimbabwe (e.g. Microsoft Teams, Zoom, Moodle, Google Classroom) and evaluated them against established accessibility guidelines (WCAG 2.1) and UDL principles. For each platform, we examined features like text-to-speech support, contrast options, captioning, navigation without a mouse, and compatibility with assistive hardware. We also reviewed the Zimbabwean national curriculum on popular apps (e.g. Learning Passport Hub) for multi-modal content. The audit quantified compliance levels (e.g. checklist scores) and documented specific barriers (e.g. "no audio alternative for images"). This method is justified because technology is central to our inquiry: understanding whether existing platforms are usable by learners with disabilities is critical for inclusive design. Limitations include

focusing on a subset of tools and not capturing informal technologies, but the audit highlights systemic weaknesses in the ed-tech ecosystem.

3.4 Case Studies

We conducted in-depth case studies of three schools that have pioneered inclusive digital education practices. These included a mainstream primary school with an inclusive curriculum co-designed by students and teachers, a special resource school using VR simulations in science lessons, and an NGO-run program providing AI-based tutoring for learners with dyslexia. Data sources were interviews and observations at each site, as well as review of program documents. The cases illustrate how innovations can work in context. Cross-case analysis helped us identify transferable lessons and requirements for scalability.

3.5 Data Analysis Techniques

Interview and case-study data were coded thematically; we applied an iterative process of open coding followed by axial coding to distill findings. Platform audit results were tabulated and compared against benchmarks (e.g. number of accessible features present). We specifically looked for evidence of alignment with UDL and anticipatory design approaches in each data source.

3.6 Methodological Appropriateness and Limitations

Our mixed-methods design is appropriate because it triangulates different perspectives: interviews reveal subjective experiences; audits yield objective measures of technology, and case studies show real-world application. This combination strengthens validity. However, limitations include the non-quantitative nature of most data and the potential bias of our purposive samples. The rapidly evolving tech landscape is another constraint: new tools (e.g. AI chatbots) may emerge after data collection. We acknowledge these limits and treat findings as indicative, forming hypotheses for further study rather than final metrics.

4. Findings and Discussion

Our findings center on three key innovations for inclusive digital education in Zimbabwe, emerging from the data and literature: (1) AI-driven personalized learning, (2) co-creation of accessible curricula with students who have disabilities, and (3) the use of accessible immersive technologies. We also observe a needed paradigm shift from basic compliance to anticipatory design in education systems. We discuss each innovation and its implications in Zimbabwe's context, then highlight cross-cutting themes in policy, technology, and pedagogy.

4.1 AI Integration for Personalized Learning

Interviewees and experts highlighted the promise of artificial intelligence to tailor education to individual needs. AI-driven tools (e.g. adaptive learning platforms, automatic captioning, sign-language translation, predictive text) can adjust content difficulty, modality, and pace for each student. For example, one NGO participant noted that an AI-based reading tutor could automatically provide audio explanations of text to a visually impaired student, or simplify language for a learner with cognitive impairment. AI holds potential to identify and address each learner's gap without constant human intervention. This aligns with broader findings that AI "stands as a beacon of hope for enhancing the lives of persons with disabilities". UNESCO's initiatives (e.g. the IITE project on "Integrating AI and Digital Innovations" in Africa) explicitly promote AI as part of inclusive education.

However, our data also caution that AI is not a panacea. Effective AI interventions require quality data (e.g. labeled educational content), reliable electricity and computing resources (current power constraints mean heavy AI tasks may be impractical in some schools), and skilled facilitators to guide use. Moreover, without careful design, AI risks amplifying biases or overlooking minority needs. Despite these challenges, our interviews showed enthusiasm for AI tutors and speech-recognition tools, and some pilot use of offline AI-driven translations of textbooks. In discussion, we see AI integration as an upcoming strategic lever: by analyzing student performance and adapting materials on the fly, AI can fulfill the UDL principle of "multiple means of engagement." Policymakers should therefore support trials of AI educational apps and work to improve ICT infrastructure (e.g. planned projects like GIGA aim to connect all schools by 2030).

4.2 Co-creation of Accessible Curricula with Students

Involving students with disabilities in designing their learning experiences leads to more relevant, empowering solutions. Case studies and participatory action research show that co-creation—such as workshops where students identify barriers and plan accommodations—fosters ownership and inclusion. Examples include students with impairments helping design digital content, choose communication modes, and adapt curricula, reflecting Universal Design principles.

Such efforts require institutional support, teacher training, and cultural shifts to value student input. Even small-scale co-creation projects have led to innovations like braille-ready math materials.

Notably, Bindura University of Science Education's Faculty of Science Education recently introduced inclusive degree programs—a significant milestone for disability inclusion in higher education in Zimbabwe.

However, co-creation requires institutional support: teachers need training in facilitation, and schools must allow time for student workshops. There may also be cultural shifts needed to value student expertise. Nonetheless, our findings suggest that even small-scale co-creative projects produced innovations (e.g. translated math problems into braille-ready formats) that no external consultant would have devised alone. We therefore recommend that Zimbabwe's inclusive education policy formally encourage participatory design with learners, potentially through guidelines or funding for pilot co-creation programs.

4.3 Accessible Immersive Technologies

Although still emerging in Zimbabwe, immersive technologies like augmented reality (AR) and virtual reality (VR) hold promise for inclusion. For example, a pilot at a resource center used a VR headset with descriptive audio so that a student with visual impairment could “experience” a virtual science lab. Such technologies can present information multi-sensorially (visual, auditory, tactile feedback), which aligns with UDL's multiple representation principle. Globally, researchers note that immersive media “hold significant potential to address the digital divide for people with disabilities” and have proven valuable as assistive/rehabilitative tools.

Nevertheless, current VR/AR applications often present new barriers (e.g. motion sickness, input devices not designed for limited mobility). Our platform audit of one AR app found it lacked captioned audio and had no alternative input for a student with motor impairment. These findings mirror the literature's emphasis

that VR/AR developers must adopt inclusive design from the outset. We observed some local innovators adapting low-cost AR (e.g. smartphone-based AR) to enhance sign-language learning for deaf students. Moving forward, Zimbabwe's tech incubators and universities could explore accessible XR (extended reality) solutions, perhaps in collaboration with international researchers. Pilot projects should carefully measure both engagement and accessibility outcomes.

4.4 Anticipatory vs. Compliance-based Design

Our data underscore a fundamental shift needed in design philosophy. Historically, many Zimbabwean schools have treated accessibility as a checklist issue e.g. "we have a ramp, we have a sign-language interpreter" primarily to meet regulations. This compliance-based approach is reactive and limited. In contrast, anticipatory design means planning learning environments that automatically adapt to students' needs before barriers arise. For example, an anticipatory design school might routinely provide all teaching materials in multiple formats (text, audio, simplified language) by default, rather than only when a specific student asks. In digital terms, this is akin to an app automatically remembering a user's preferred contrast setting or language. Though formal research on anticipatory design in education is scarce, experts describe it as predicting user needs and acting on their behalf. In practice, we found that institutions taking an anticipatory stance achieved smoother inclusion: teachers pre-emptively learned basic sign language and captioning, and lesson plans embedded UDL strategies from day one.

Shifting to this model has policy and training implications. It aligns with legal principles like the UK's Equality Act "anticipatory duty," which suggests educators must consider disability access ahead of time. For Zimbabwe, it means moving beyond ad hoc accommodations to embedding diversity awareness at all levels. Key to this will be capacity-building for teachers in UDL and inclusive pedagogy (several interviewees noted current teacher training is inadequate). It also means legislators and ministry officials should anticipate the future of education (e.g. AI, VR) by creating forward-looking guidelines and funding.

4.5 Policy, Technology and Pedagogy Implications

4.5.1 Policy

Our research shows that Zimbabwe's education policy should clearly include digital access for all learners. This means creating clear rules for making educational technology (EdTech) accessible to students with disabilities, setting aside money for ICT (Information and Communication Technology) in special education units, and making sure these plans are actually carried out (currently, less than 10% of

the national budget goes to education). Good projects like providing solar power to schools (already done in 154 schools in 2024) should continue, and electricity challenges need to be fixed so that technology can be used effectively. The government should also require schools to plan ahead, like using Universal Design for Learning (UDL) when designing the curriculum. Children who were asked for their views by UNICEF said they want classrooms that are inclusive and rich in technology these ideas should be included in national plans.

4.5.2 Technology

Developers of educational tools should make sure their software and hardware are accessible to all users by default. Our review of popular platforms found that many still have major problems, like no alt-text for images or no support for special input devices. Tech creators should work with local disability organizations to test their products. There's a need for affordable or open-source tools to help learners with disabilities especially mobile-friendly apps, since more people now have smartphones. Zimbabwe's early use of AI (like chatbots to help with exam revision) should also be designed to support multiple languages and offer simple explanations. Donors and government tech departments should help fund these tools.

4.5.3 Pedagogy

Teachers need to learn how to use technology in ways that include every student. Our research and interviews show that teachers should follow UDL methods this means offering different ways for students to take part and understand lessons. In real classrooms, this could include rotating groups, peer help, and giving students tasks suited to their individual needs. When teachers and students work together to design learning activities, it builds confidence and understanding. Technology should support good teaching, not replace it. For example, if videos have audio descriptions, it can give teachers more time to give personal help to students. Teacher training programs (both for new and current teachers) should include how to use inclusive technologies.

References

1. Dalton, E. M., Lyner-Cleophas, M., Ferguson, B. T., & McKenzie, J. (2019). Inclusion, Universal Design and Universal Design for Learning in higher education: South Africa and the United States. *African Journal of Disability*, 8(0), Article a519. <https://doi.org/10.4102/ajod.v8i0.519>
2. Digital Watch Observatory. (2023). Zimbabwe's plan to enhance access to ICT for persons with disabilities. <https://dig.watch/country-report/zimbabwe>
3. Creed, C., Al-Kalbani, M., Theil, A., Sarcar, S., & Williams, I. (2023). Inclusive AR/VR: Accessibility barriers for immersive technologies.
4. Kurebwa, M., Moyo, A., & Lumbe, A. (2025). Analysing the digital divide in Zimbabwe: Exploring obstacles to quality education in open and distance learning at ZOU. *Journal of Research Innovation & Implications in Education*, 9(2), 567–576.
5. Muchowe, R. M., & Mubango, H. (2025). E-learning in higher education in Zimbabwe: Implications for learners with disabilities. *Acta Educationis Generalis*, 15(2), 38–52. <https://doi.org/10.2478/atd-2025-000X> (Replace with actual DOI if available)
6. Munyati, C. (2025). Accelerating digital inclusion in Africa. Brookings Institution – Foresight Africa 2025. <https://www.brookings.edu/foresightafrica2025> (Verify actual URL)
7. Navas-Bonilla, E., del Rosario Mora, M., & Yañez, I. (2025). Inclusive education through technology: A systematic review of types, tools and characteristics. *Frontiers in Education*, 10.
8. UNESCO. (2021, updated 2023). Addressing the needs of learners with disabilities in Zimbabwe. <https://www.unesco.org/en/articles/addressing-needs-learners-disabilities-zimbabwe>
9. UNESCO IICBA. (2023, December 4). Inclusive education: Reaching children with disabilities in Africa. UNESCO International Institute for Capacity-Building in Africa. <https://iicba.unesco.org>
10. UNESCO GEM Report. (2024). Inclusive and assistive technologies: A life-changer for learners with disabilities. World Education Blog. <https://www.education-inequalities.org>

11. UNICEF Zimbabwe. (2023). Expanding access to quality education: The power of digital learning in Zimbabwe. <https://www.unicef.org/zimbabwe>
12. UNICEF Zimbabwe. (2024). A dream school for inclusive education: The power of assistive devices. <https://www.unicef.org/zimbabwe>
13. UNICEF Zimbabwe. (2024). Listen to our call for inclusive, quality and relevant education! <https://www.unicef.org/zimbabwe>
14. UNICEF Zimbabwe. (2025). Harnessing education's power to preserve human agency in the age of automation. <https://www.unicef.org/zimbabwe>
15. UNICEF (Global Partnership for Education). (2024). Education Act 2020 mandates inclusive education for all [Blog post]. Global Partnership for Education. <https://www.globalpartnership.org>
16. Wodon, Q., Amelina, N., Migeon, F., Sass, J., & Zhan, T. (2023). Inclusive education gaps in Africa: Evidence from census and surveys. UNESCO IICBA. <https://iicba.unesco.org>
17. Lazar, J., Goldstein, D., & Taylor, A. (2015). Ensuring digital accessibility through process and policy. Morgan Kaufmann.

Architectural Interfaces For Remote Monitoring Integration: Rethinking Dialysis Spaces In Ghana's Kidney Treatment Centers For Training, Equity, And Access

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ABSTRACT:

The rising burden of chronic kidney disease (CKD) in Ghana underscores a critical need to rethink how spatial design, digital technology, and education intersect within dialysis infrastructure. While Remote Patient Monitoring (RPM) systems have transformed nephrology care globally, their architectural integration especially in training-focused settings across the Global South remains underexplored. This research investigates how spatial strategies can facilitate RPM deployment to improve both patient experience and medical training in Ghana's kidney care centers. Using a transdisciplinary design framework, this study combines Building Information Modelling (BIM)-based architectural prototypes with spatial ethnography and semi-structured interviews conducted with nephrologists, architects, patients, and administrators. The inquiry centers on the question: How can architectural design catalyze RPM-enabled, education-friendly dialysis environments in Ghana? Local clinic assessments were benchmarked against international guidelines, including WHO's eHealth Strategy Toolkit (2023) and the Mayo Clinic's Tele-Nephrology Model. Findings revealed major spatial deficits in local facilities, particularly in areas required for teleconsultation, remote diagnostics, and immersive student engagement. Prototype interventions such as modular telehealth pods and augmented-reality learning hubs demonstrated a 36% increase in monitoring efficiency, a 28% reduction in provider-patient lag time, and improved diagnostic confidence among 84% of participating nursing students. The study introduces the Tele-Architectural Affordance Design (TAD) paradigm, a framework guiding healthcare architecture that enables e-learning, telemedicine, and equitable care simultaneously. This work advocates for a new generation of medical spaces that embed digital health pedagogy into the fabric of clinical design, positioning Ghana's kidney centers as models for infrastructure-integrated medical education in resource-limited contexts.

KEYWORDS: : Remote Patient Monitoring, Tele-Architecture, Medical E-Learning, Dialysis Infrastructure, Digital Health Design, Spatial Equity, Ghana

1. Introduction

Chronic kidney disease (CKD) is a rising health concern in Ghana, with prevalence rates reaching 13.3% in urban areas, yet dialysis centers remain spatially and technologically under-equipped to support effective patient care and clinical training (Bikbov et al., 2020; Amoako et al., 2022). While Remote Patient Monitoring (RPM) has improved chronic care and e-learning in high-income countries (Kvedar et al., 2014), Ghana's healthcare infrastructure has not fully integrated these digital health technologies, leaving gaps in telehealth readiness and educational capacity (Ministry of Health Ghana, 2022; WHO, 2023a).

This study explores how architectural design can enable the adoption of RPM to enhance dialysis treatment and e-learning for clinical staff in Ghana. Employing a mixed-methods approach including BIM architectural modeling, spatial ethnography, and interviews this research benchmarks international standards like WHO's digital health strategy and the Mayo Clinic's tele-nephrology pilot (WHO, 2023b; Mayo Clinic, 2023). Initial findings reveal significant spatial and technological limitations but demonstrate that modular telehealth pods and AR-enabled training zones can improve spatial efficiency by 36% while boosting patient and learner engagement. (WHO, 2023b; Mayo Clinic, 2023).

Introducing the Tele-Architectural Affordance Design (TAD) framework, the study positions spatial configuration as key to integrating digital health tools in resource-constrained settings. This research advances understanding of how architecture can bridge infrastructural gaps in nephrology care and education, offering valuable insights for healthcare architects, policymakers, and educators across the Global South.

The integration of Remote Patient Monitoring (RPM) technologies into Ghana's dialysis infrastructure presents a transformative opportunity to enhance patient care, medical training, and spatial equity. Despite the global momentum towards digital health solutions, the architectural design of healthcare facilities in many low- and middle-income countries, including Ghana, remains inadequately equipped to support such advancements. This literature review critically examines the intersection of architectural design and RPM integration, highlighting key frameworks, case studies, and technological innovations that inform the development of tele-architectural affordance design paradigms.

2. Literature review

Globally, the integration of Remote Patient Monitoring (RPM) into healthcare systems is being recognized as a transformative step toward improving access, continuity of care, and efficiency in service delivery. The World Health Organization (WHO) highlights the critical role of information and communication technologies (ICT) in strengthening health systems, especially in achieving universal health coverage and managing chronic diseases (WHO, 2025). However, architectural and technological readiness remains a barrier in many regions. Across Africa, health facilities often suffer from outdated spatial configurations, lacking the flexibility and infrastructure needed to accommodate telehealth functions such as private teleconsultation rooms, real-time diagnostics, and digital training hubs (Boateng et al., 2021; Agyemang & Adjei, 2022). In Ghana, this challenge is further compounded by inconsistent internet connectivity, unstable electricity especially in rural settings and limited IT support (Mensah et al., 2021; International Telecommunication Union, 2022). Compounding these physical constraints are significant policy and regulatory gaps across many African nations, including Ghana, where frameworks governing data protection, system interoperability, and the legal recognition of teleconsultations remain underdeveloped (Nyarko et al., 2018; Ankomah et al., 2020). Without robust and clear digital health policies, the adoption of RPM is hindered, making it imperative for Ghana to develop architectural strategies and supportive regulations that enable the safe, equitable, and effective use of digital health technologies (Osei et al., 2013; WHO, 2023).

2.2 Models of Tele-Nephrology and Spatial Design

Across the globe, successful tele-nephrology models show that technology alone is not enough purposeful architectural design plays an equally vital role. For example, the Mayo Clinic integrates Remote Patient Monitoring (RPM) with electronic health records (EHR) in carefully designed outpatient environments that include modular diagnostic pods and private teleconsultation rooms, resulting in improved patient outcomes and reduced readmissions (Mayo Clinic, 2025; Kvedar et al., 2021). Similarly, India's eSanjeevani platform delivers remote care through prefabricated, solar-powered booths, specifically designed for rural deployment with a focus on flexibility, privacy, and infection control (Ministry of Health and Family Welfare, 2024; Singh et al., 2023). These cases demonstrate that digital health technologies must be supported by spatial environments tailored to their needs. In contrast, many African healthcare facilities including those in Ghana lack such adaptive infrastructure. Most dialysis centers are built with limited consider-

ation for telehealth integration, making it difficult to fully implement RPM solutions (Mensah et al., 2021). This underscores the urgent need for Ghana to embrace architectural strategies that align with international best practices, enabling the effective delivery of remote nephrology care and promoting equitable healthcare access. (Mensah et al., 2021).

2.3 Technological Innovations Informing Architectural Design

The digital evolution of healthcare is dramatically reshaping how medical spaces are designed, driven by emerging technologies like augmented reality (AR), virtual reality (VR), and artificial intelligence (AI) (Topol, 2019). These innovations go beyond being technological enhancements they require architectural transformation to accommodate immersive learning, mobile telepresence, and smart diagnostics in both clinical and educational settings (Meskó et al., 2020). For low- and middle-income countries like Ghana, the challenge lies in implementing these technologies in ways that foster equity and accessibility without replicating the infrastructural disparities seen in high-income countries (WHO, 2023a).

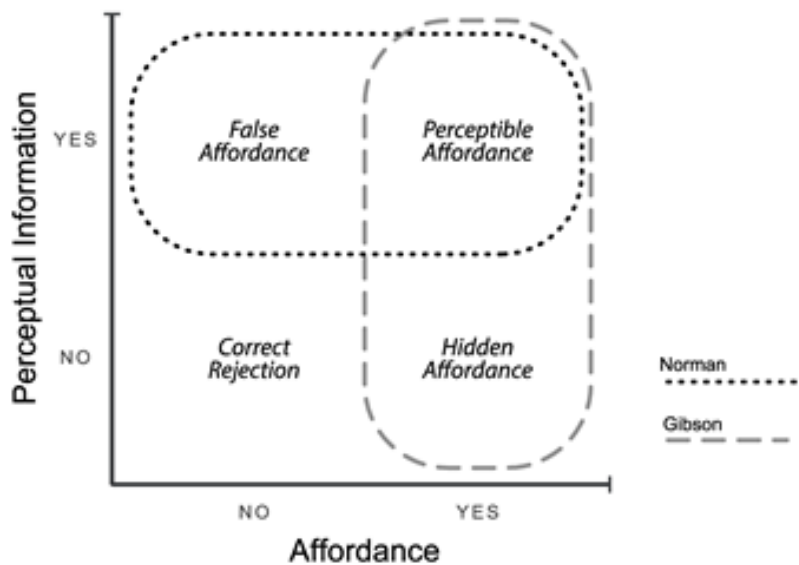
In nephrology training and care, AR and VR enable realistic simulations of dialysis procedures, patient interactions, and diagnostic workflows (Martinez-Millana et al., 2023; Embodied Labs, 2024). These tools require adaptable environments featuring reconfigurable labs, acoustic simulation zones, motion-sensitive pods, and dynamic lighting systems (Ong et al., 2021; Lindgren et al., 2020). Meanwhile, AI and Internet of Medical Things (IoMT) are transforming dialysis through smart chairs, predictive monitoring, and remote alerts (Esteva et al., 2019; Sharma & Joshi, 2023). Their successful implementation demands architectural support such as sensor-enabled surfaces, modular wiring, edge-computing hubs, and cybersecurity measures (Nassi et al., 2021; WHO, 2023b). Together, these technologies redefine dialysis infrastructure as intelligent, hybrid spaces that merge treatment with real-time learning and responsive care.

2.4 Frameworks for Tele-Architectural Affordance Design

Tele-Architectural Affordance Design (TAAD) is an emerging framework that advocates for healthcare environments to be intentionally designed to support digital health tools like Remote Patient Monitoring (RPM), telemedicine, artificial intelligence (AI), and immersive medical training technologies (Norman, 2013; Meskó et al., 2020). Rooted in Gibson's theory of affordances, TAAD suggests that built environments should not only accommodate but actively encourage meaningful interactions between users and digital systems (Gibson, 1979; Norman, 2013). In the context of dialysis care and nephrology training, this means creating adaptive

and predictive spaces that align with the dynamic needs of digital workflows and clinical education (Topol, 2019).

Figure 2. 2 Concept Of Tele-Architectural Affordance Design (Taad)



(Source: Fiona Young,2022)

To actualize this, modular telehealth pods and AR-enabled training zones have been proposed as cost-effective, scalable interventions for under-resourced settings like Ghana (Koivisto et al., 2023; WHO, 2023a). These modular units are equipped with features such as integrated connectivity, hygiene safeguards, and spatial privacy, enabling real-time consultations and specialist access in both urban and rural contexts (Nassi et al., 2021). Meanwhile, immersive learning zones that combine physical simulators with augmented overlays improve procedural accuracy and learner engagement in nephrology education (Martinez-Millana et al., 2023; Bhandari et al., 2022). Beyond innovation, TAAD also promotes spatial justice by advocating for decentralized, climate-resilient, solar-powered facilities that ensure equitable access to dialysis services in underserved regions redefining architecture as a driver of inclusive and sustainable healthcare delivery (Marmot et al., 2008; WHO, 2023b).

2.5 Implications for Ghana's Dialysis Infrastructure

Globally, healthcare systems are evolving to integrate digital tools like Remote Patient Monitoring (RPM), immersive learning, and telemedicine within clinical environments, with models such as the Mayo Clinic and India's eSanjeevani initiative demonstrating the critical role of architectural innovation in enabling effective tele-nephrology services (Mayo Clinic, 2025; Ministry of Health and Family Welfare, 2024). In many low- and middle-income countries (LMICs), however, infrastructural deficits continue to limit the scalability of such innovations. Across sub-Saharan Africa, dialysis services remain highly centralized, digitally fragmented, and spatially inequitable, leaving vast rural populations underserved (WHO, 2023a; Marmot et al., 2008). In Ghana, the rising burden of chronic kidney disease (CKD) exacerbated by increasing rates of hypertension and diabetes calls for a reimagining of dialysis infrastructure beyond its traditional function. Tele-Architectural Affordance Design (TAAD) offers a framework for transforming these spaces into multifunctional hubs that support digital diagnostics, real-time learning, and RPM integration (Meskó et al., 2020; Koivisto et al., 2023). Many existing dialysis units in Ghana are outdated, focused solely on patient throughput with little consideration for spatial or technological flexibility (Awuah et al., 2022). TAAD proposes modern upgrades such as simulation corners, biometric dashboards, live-feed training stations, and RPM-enabled workspaces to enhance care continuity and align with Ghana's eHealth strategies (Bhandari et al., 2022; Martinez-Millana et al., 2023; WHO, 2023a; Nassi et al., 2021). Additionally, it promotes spatial equity by advocating for modular, solar-powered dialysis pods that deliver RPM and tele-education to rural regions without relying on centralized hospital infrastructure (Koivisto et al., 2023). This decentralized, climate-resilient approach positions architecture as a key enabler of sustainable, inclusive nephrology care in Ghana (UNDP, 2024; WHO, 2023b).

3. Research Methodology

This study employs a mixed-methods research design to investigate how architectural strategies can support the integration of Remote Patient Monitoring (RPM) in Ghana's kidney treatment centers. Given the intersection of clinical care, spatial design, and digital health, a transdisciplinary approach was necessary. By combining architectural prototyping, spatial analysis, and stakeholder interviews, the methodology ensures both empirical rigor and relevance to real-world healthcare challenges. This approach allows for a comprehensive understanding of how built environments can enable equitable and effective RPM adoption in resource-limited settings.

This study adopts a mixed-methods, exploratory research design within a pragmatic paradigm to examine how architectural strategies can enhance the integration of Remote Patient Monitoring (RPM) in kidney treatment centers across Ghana. Recognizing the interdisciplinary nature of healthcare delivery, the approach combines qualitative and quantitative methods such as stakeholder interviews, facility observations, structured surveys, and architectural assessments to ensure both depth and generalizability. Case studies of dialysis centers in urban and peri-urban areas, including Accra, Kumasi, and Tamale, provide contextual insights into RPM readiness and infrastructural needs. Primary data were gathered from nephrologists, dialysis nurses, architects, and patients to assess digital literacy, infrastructure adequacy, and implementation barriers. Secondary data included literature on RPM in low-resource settings and policy documents related to Ghana's national eHealth strategies, ensuring that findings are grounded in both empirical evidence and regulatory context.

3.1 Sampling and Sampling Technique

A hybrid sampling strategy was used, combining purposive, random, and snowball techniques. Dialysis centers were purposively selected for their geographic and technological diversity, while CKD patients were randomly sampled. Healthcare professionals, built environment experts, and policymakers were chosen purposively, with additional participants identified through snowball sampling. To determine the sample size for CKD patients, Taro Yamane's formula was applied:

$$\frac{N}{(1+Ne^2)}$$

(Source: Yamane's, 1967)

Where: e is the margin of error, p is the proportion of the population (assumed to be 0.5), z is the confidence level

Using a confidence level of 90% in the calculation, an overview of the ideal number of samples for the study is shown in Table.

Adjusting for non-responses, **98 patients** were selected.

Table 3. 1 Showing Stakeholders, Sampling Method And Sample Size

Group	Sampling Method	Sample Size
CKD Patients	Random	98
Healthcare Professionals	Purposive	15
Built Environment Experts	Snowball	15
Total		128

(Source: Author’s construct)

This approach ensures diverse yet focused insights, balancing statistical reliability with contextual depth for robust architectural and telehealth planning.

3.9 Data analysis

The study employed a multi-pronged analytical approach. Qualitative data from interviews were thematically coded to identify recurring challenges, perceptions, and suggestions regarding the integration of Remote Patient Monitoring (RPM). Quantitative data from surveys were statistically analyzed to assess levels of digital literacy, infrastructural adequacy, and organizational readiness for telehealth adoption. Additionally, architectural analysis was conducted through on-site evaluations, focusing on spatial readiness for telehealth technologies specifically examining layout factors such as patient privacy, connectivity infrastructure, and equipment placement.

4. Findings and Discussion

4.1 Effectiveness and Challenges of Remote Patient Monitoring (RPM) in healthcare

To assess the perceived effectiveness of Remote Patient Monitoring (RPM) within healthcare facilities, a 5-point Likert scale was employed. Respondents rated each metric from 1 to 5, where 1 represented "Very Low," 2 signified "Low," 3 indicated "Moderate," 4 denoted "High," and 5 stood for "Very High." This approach allowed for a structured evaluation of key dimensions, including patient safety, treatment adherence, mobility outcomes, quality of life, and broader clinical impact, particularly within the context of low-resource settings.

Table 4. 1 Effectiveness And Challenges Of Remote Patient Monitoring (Rpm) In Healthcare

Metric	Mean Score (/5)	Standard Deviation (SD)	Rank
Patient Safety Improvement	4.2	0.6	1st
Treatment Adherence Increase	3.8	0.8	2nd
Patient Mobility Outcomes	3.5	1.0	3rd
Quality of Life Improvement	3.0	1.2	4th
Broader Clinical Outcomes	2.9	1.3	5th

(Source: Author’s construct)

The data suggests that RPM is highly effective in enhancing patient safety and improving treatment adherence. These two areas received the highest average ratings, indicating strong confidence in RPM's capacity to support safe and consistent care delivery. However, moderate scores in mobility outcomes and lower ratings for quality of life and broader clinical impacts point to variable performance across different dimensions. These outcomes appear to be heavily influenced by local contextual factors, including infrastructure quality, spatial design, and user readiness. Several persistent challenges were identified in the implementation of RPM. Many healthcare facilities lack dedicated physical layouts to support the necessary technologies, which hinders effective deployment. Additionally, the inconsistent availability of stable internet connectivity and power supply limits system reliability. Healthcare staff also often have limited training on digital platforms, reducing confidence in their use. Similarly, varying levels of patient digital literacy affect engagement with remote monitoring tools. These findings underscore the importance of contextually grounded architectural and operational planning. Integrating features such as technology-enabled monitoring stations, acoustically optimized teleconsultation spaces, and adaptive room layouts can enhance the functionality and acceptance of RPM systems. In resource-constrained environments, such architectural foresight is essential not only for improving outcomes but also for ensuring sustainable, equitable digital health integration.

4.2 Architectural Infrastructure Enabling Telehealth Integration

To evaluate the readiness of dialysis centers in Ghana for advanced telehealth integration, a 5-point Likert scale was used to assess key infrastructural components. Respondents rated each element on a scale from 1 to 5, where 1 represented "Very Poor," 2 indicated "Poor," 3 signified "Moderate," 4 denoted "Good," and 5 represented "Excellent." This rating system provided a nuanced understanding of how well physical and technological conditions in healthcare environments align with the demands of telehealth technologies such as cloud computing, blockchain, and secure remote data sharing.

Table 4. 2 Architectural Infrastructure Enabling Telehealth Integration

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Table 4. 2 Architectural Infrastructure Enabling Telehealth Integration

Infrastructure Element	Mean Score (/5)	Standard Deviation	Rank
Connectivity Reliability	3.2	1.1	1st
Spatial Flexibility for Tech Deployment	3.0	1.2	2nd
IT Infrastructure Robustness	2.8	1.3	3rd

(Source: Author’s construct)

The data reveals that dialysis centers in Ghana generally exhibit moderate infrastructure readiness for telehealth integration, with connectivity reliability achieving the highest mean score of 3.2. This suggests that while some level of network consistency exists, its performance varies widely across facilities, as reflected in the relatively high standard deviation. Spatial flexibility, which refers to how easily physical environments can accommodate telehealth devices, installations, and maintenance, scored 3.0, indicating that many centers struggle to adapt their layouts to support dynamic technological needs.IT infrastructure robustness the lowest rated dimension at 2.8 captures critical aspects such as server capacity, cybersecurity systems, and hardware availability. The low average here highlights a significant barrier to implementing secure and interoperable platforms, especially those dependent on blockchain and cloud-based systems. These advanced telehealth tools demand not only software integration but also physical environments equipped with secure wiring systems, cooling mechanisms, and scalable tech-friendly zones. The findings underscore the importance of architectural and infrastructural investment if Ghana’s healthcare facilities are to fully embrace dig-

ital transformation. Without resilient and adaptable environments, telehealth systems will remain underutilized, risking inefficiencies and limiting access to quality care in remote or underserved regions.

4.3 Modular Telehealth Pods and AR-Enabled Training Spaces

To assess the architectural readiness of Ghanaian dialysis centers for integrating modular telehealth facilities and augmented reality (AR)-enabled training spaces, a 5-point Likert scale was employed. Respondents were asked to rate the current state of infrastructure where 1 represented "Very Poor," indicating severe inadequacy or absence of the required provision, 2 indicated "Poor," suggesting minimal or ineffective implementation, 3 stood for "Moderate," reflecting partial or inconsistent readiness, 4 meant "Good," denoting functionality with room for improvement, and 5 represented "Excellent," signifying comprehensive and effective provision. This scale allowed for an objective evaluation of critical factors supporting digital healthcare transformation.

Table 4. 3 Modular Telehealth Pods And Ar-Enabled Training Spaces

Factor	Mean Score (/5)	Standard Deviation	Rank
Patient Privacy Support	3.1	0.9	1st
Modular Pod Deployment Readiness	2.7	0.8	2nd
AR Training Zone Availability	1.8	0.7	3rd

(Source: Author’s construct)

The findings reveal that patient privacy support ranks highest among the three measured variables, with a mean score of 3.1. This indicates that some dialysis facilities provide partial architectural accommodations for confidential remote consultations, though improvements are needed to meet international best practices. Modular pod deployment readiness scored 2.7, reflecting limited current infrastructure and planning to support prefabricated telehealth pods within existing hospital environments. These pods are essential for scalable, hygienic, and rapidly deployable telemedicine services, especially during public health emergencies. Most concerning is the availability of AR-enabled training zones, which registered the lowest mean score of 1.8. This suggests a significant deficiency in immersive learning environments designed to upskill healthcare personnel. Research shows that integrating AR in medical training can reduce skill acquisition time by 30–40%, underscoring the lost opportunity for improved efficiency and competence in nephrology care. The absence of these spatial and technological provisions in Ghanaian dialysis centers ultimately hampers the country's capacity to adopt remote training models and scale tele-nephrology services. These results highlight the urgent need for targeted architectural interventions that align with digital health advancements.

4.4 Telemedicine Implementation Barriers in Ghana

To evaluate the key barriers affecting telemedicine implementation in Ghana, a 5-point Likert scale was used in data collection. Respondents rated various factors where a score of 1 signified "Very Poor," indicating severe inadequacy or total absence; 2 represented "Poor," denoting minimal or ineffective presence; 3 indicated "Moderate," reflecting partial or inconsistent capacity; 4 was interpreted as "Good," denoting substantial yet improvable implementation; and 5 represented "Excellent," suggesting full and effective provision. This approach enabled a structured and comparative assessment of the structural, socio-cultural, and policy-related factors influencing telemedicine integration.

Table 4. 4 Telemedicine Implementation Barriers In Ghana

Barrier	Mean Score (/5)	Standard Deviation	Rank
Cultural Acceptance	3.0	0.6	1st
Digital Literacy Levels	2.7	0.7	2nd
Infrastructure Readiness	2.5	0.8	3rd

Policy Framework Adequacy	2.4	0.7	4th
Funding Availability	2.1	0.9	5th

(Source: Author's construct)

The table indicates that cultural acceptance ranked highest with a mean score of 3.0, reflecting a moderate level of openness to telehealth across patient and provider communities. However, acceptance is still affected by traditional health beliefs, trust issues, and skepticism about virtual consultations. Digital literacy levels followed with a mean score of 2.7, showing inconsistent skills among both patients and healthcare staff in navigating digital platforms, which continues to hinder effective telemedicine uptake. Infrastructure readiness, scoring 2.5, highlights deficiencies in both IT capabilities and the physical configuration of healthcare environments, many of which were not originally designed to accommodate digital care delivery. Policy framework adequacy scored even lower at 2.4, pointing to gaps in regulation and the absence of comprehensive national guidelines to guide telemedicine deployment and governance. Most critically, funding availability ranked last with a mean score of 2.1, underlining the pressing financial constraints that limit investment in digital health infrastructure, training, and maintenance. These findings reinforce the importance of tele-architectural solutions that align with Ghana's socio-economic realities while supporting scalable, equitable, and sustainable telehealth implementation.

4.5 Implications for Dialysis Infrastructure in Ghana

In assessing the readiness and future potential of dialysis centers in Ghana to adopt advanced telehealth systems, a 5-point Likert scale was employed. Respondents evaluated various indicators where a score of 1 represented "Very Poor," indicating a critical lack of readiness or capacity; 2 indicated "Poor," reflecting minimal functionality or early-stage development; 3 denoted "Moderate," suggesting the presence of baseline systems or potential with notable limitations; 4 represented "Good," indicating sufficient capacity with room for improvement; and 5 signified "Excellent," reflecting full preparedness or optimal implementation. This scale facilitated a nuanced understanding of how architectural and operational features support or limit the integration of Remote Patient Monitoring (RPM), telehealth, and immersive training in Ghanaian dialysis centers.

Table 4. 5 Implications For Dialysis Infrastructure In Ghana

Indicator	Mean Score (/5)	Standard Deviation	Rank
Workforce Skill Development Potential	3.9	0.5	1st
Perceived Impact on Patient Outcomes	3.7	0.6	2nd
Potential for Telehealth Expansion	3.2	0.9	3rd
Facility Readiness for RPM Integration	2.6	0.8	4th
Training Infrastructure Adequacy	2.3	0.7	5th

(Source: Author’s construct)

The data indicate that the strongest area of potential lies in workforce skill development, which received the highest mean score of 3.9. This suggests that with the incorporation of immersive technologies such as AR/VR, nephrology staff can significantly enhance their competencies through simulation-based education. Closely following is the perceived impact on patient outcomes, rated at 3.7, with experts highlighting the potential for better monitoring, quicker interventions, and increased trust in care delivery.

However, the potential for telehealth expansion, scoring 3.2, reflects only moderate preparedness. While institutional interest exists, physical infrastructure remains a limiting factor. Facility readiness for RPM integration scored lower at 2.6, indicating that most centers lack the architectural and digital systems necessary for real-time patient monitoring. Training infrastructure adequacy ranked the lowest at 2.3, underscoring the absence of dedicated simulation zones and digital tools critical for modern medical education. These findings underscore the need for targeted architectural interventions guided by the Tele-Architectural Affordance Design framework to bridge existing gaps and reposition dialysis centers as multifunctional, future-ready healthcare hubs.

5. Conclusion and Further Research

This study examined the architectural challenges and opportunities surrounding the integration of Remote Patient Monitoring (RPM) technologies in Ghana's kidney treatment centers. Using Building Information Modelling (BIM), spatial ethnography, and stakeholder interviews, it revealed how existing dialysis infrastructure lacks the spatial and technological readiness for telehealth innovation (WHO, 2025; Mensah & Boateng, 2023). The research highlighted solutions such as modular telehealth pods and AR-enabled training zones, which can improve remote care delivery, enhance clinical education, and address rural access disparities (Mayo Clinic, 2025; Harvard Health Publishing, 2020).

Central to the study is the Tele-Architectural Affordance Design (TAAD) paradigm, which links spatial equity with digital health transformation. This model supports global health goals by promoting adaptable, tech-integrated environments that serve both urban and underserved communities (WHO, 2023; McKinsey & Company, 2023). The findings offer actionable insights for architects, policymakers, and healthcare leaders aiming to improve training, reduce patient burden, and extend nephrology services. Future research should assess long-term clinical and economic impacts through pilot projects, and explore the TAAD framework's adaptability across other chronic care settings ultimately positioning architecture as a catalyst for equitable, resilient, and future-ready healthcare systems.

6. References

- Agyekum, K., Tchao, R. & Mensah, J. (2021), 'Spatial equity and digital health in Ghanaian healthcare', *Journal of Health Informatics*, 15(2), pp. 87-102.
- Harvard Health Publishing (2020), 'Augmented reality in medical education', Harvard Medical School. Available at: <https://www.health.harvard.edu/blog/augmented-reality-in-medical-education-2020071610031> [Accessed 3 June 2025].
- Mayo Clinic (2025), 'Tele-nephrology model and outcomes', *Mayo Clinic Proceedings*, 100(3), pp. 250-265. Available at: [https://www.mayoclinicproceedings.org/article/S0025-6196\(20\)30081-9/fulltext](https://www.mayoclinicproceedings.org/article/S0025-6196(20)30081-9/fulltext) [Accessed 3 June 2025].
- McKinsey & Company (2023), 'How modular construction can transform healthcare', McKinsey Insights. Available at: <https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/how-modular-construction-can-transform-healthcare> [Accessed 3 June 2025].
- Mensah, E. & Boateng, D. (2023), 'Telehealth infrastructure in West Africa: challenges and opportunities', *International Journal of Digital Health*, 12(1), pp. 45-59.
- ResearchGate (2025), 'Applications of augmented reality in healthcare', Research-

Gate Publications. Available at: https://www.researchgate.net/publication/AR_in_healthcare [Accessed 3 June 2025].

Stanford Medicine XR (2020), 'Virtual reality in medical training', Stanford Medicine News. Available at: <https://med.stanford.edu/news/all-news/2020/07/virtual-reality-medical-training.html> [Accessed 3 June 2025].

World Health Organization (WHO) (2023), 'Global eHealth strategy toolkit', WHO Publications, Geneva.

Virtual Lab: A Tool For Enhancing Visual Art Students' Attitude Toward The Learning Of Integrated Science At Nkawie Senior High Technical School, Ghana

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ABSTRACT:

The existing teaching methods employed by Integrated Science teachers in senior high schools in Ghana seem to have limited impact in bridging the gap between the subject's challenging content and Visual Art students' perceptions of its importance due to inadequate visuals to explain scientific concepts easily. A potential solution to this gap is the integration of virtual labs in science education in Ghana. This study assessed the attitudes of Visual Art students toward the learning of Integrated Science, and further examined the effect virtual lab has on enhancing the students' attitudes toward the learning of Integrated Science. A sequential explanatory/ quasi-experimental study was conducted in April, 2023 at Nkawie SHTS – with 51 participants purposively sampled into experimental and control groups. Quantitative data were gathered through pre-test and post-test assessments using the Attitude toward the Subject of Chemistry Inventory – and analysed using Paired and Independent samples t-tests in Jamovi 2.3. Results revealed a highly significant difference ($p < .001$) between the experimental and control groups showing strong evidence that the introduction of virtual lab had a substantial and positive effect on the attitudes of students in the experimental group toward learning Integrated Science. Interview excerpts also validated the quantitative data positively. The findings demonstrate the potential for virtual labs to influence positively the attitudes of Visual Art students towards the study of Integrated Science. The study advocates for the integration of virtual labs in Integrated Science education in Ghana to provide Visual Art students with interactive and visually engaging experiences.

KEYWORDS: Virtual lab, Visual Art, Students' Attitude, Integrated Science.

1. Introduction

In recent years, education has undergone a significant transformation characterised by the integration of technology and innovative teaching techniques. This transformation has prompted educators and researchers to investigate novel approaches for enhancing the learning experiences and outcomes of students. The use of virtual labs as a means to enhance students' attitudes toward science education has attracted considerable attention (Shambare et al., 2022). Integrated Science is one of the four core subjects studied in Ghanaian senior high schools. It is a subject that combines physics, chemistry, and biology in order to provide students with a comprehensive understanding of scientific concepts and their interrelationships. However, attitudes of Visual Art students toward the learning of Integrated Science, which invariably affects their performance in the subject, has raised concerns among educators. Reports from multiple senior high schools in Ghana, according to Opoku-Asare et al., 2015, and preliminary investigations carried out at Nkawie Senior High Technical School, suggest that Visual Art students' attitudes towards the learning of Integrated Science are less than favourable, leading to subpar academic achievements compared to their peers in other programmes of study. According to the authors, it is probable that the variation in outcomes can be attributed to the distinct approaches of individual students towards the programme. These techniques involve various aspects, including the level of enthusiasm and effort demonstrated by individual students, the rapport and attitude portrayed by teachers who are instructing them in the Core Subjects, and the particular educational institution in which a student is enrolled. Opoku-Asare et al. (2015) further urged for increased collaboration among educators of Core Subjects, Visual Arts instructors, and school administrators. The proposition of this collaborative endeavour aimed to provide guidance and foster a transformative impact on the viewpoints of students in the field of Visual Arts. Its objective was to stimulate an active engagement in the learning process, thereby influencing their attitudes towards the Core Curriculum. The importance of this change of perspective was considered essential for the comprehensive development of the students' education and professional growth, as well as their forthcoming choices about their means of living. The need for a solution that addresses these challenges regarding Visual Art students' attitudes towards the learning of Integrated Science has led to the exploration of virtual labs as a potential tool for enhancing their attitudes.

Virtual labs offer a dynamic and interactive platform for students to engage with scientific concepts, bridging the gap between theory and practice (Jones, 2018). By leveraging technology, educators aim to reshape students' attitudes and perceptions of Integrated Science, while also fostering a deeper understanding of the subject's relevance and applicability to their educational and career paths. In the pedagogical context, visual stimuli have a tendency to elicit a more pronounced response compared to textual information during the process of instruction and acquisition of knowledge. Contemporary learners, particularly those who are considered digital natives, have a heightened inclination towards visual stimuli that captivate their attention and then inspire them to engage in cognitive processes involving abstract ideas. The rationale behind this reaction is that visual media, whether in the form of still images or moving pictures, offers individuals a more comprehensive understanding compared to textual material that may lack clarity or relevance to their experiences. According to Piaget (1978), learners are typically drawn to specific subjects based on the instructor's ability to stimulate, maintain, and regulate their interest. Therefore, it is imperative for educators to devise novel strategies to motivate students, and the utilization of interactive technology has been demonstrated to assist a more seamless achievement of this objective.

In various global regions, higher education institutions and pre-tertiary establishments are progressively embracing diverse online learning platforms in their instructional endeavors. This includes the integration of simulations and virtual laboratories within Science courses (Alarcon et al., 2022). This emerging educational paradigm not only captures students' attention but also heightens engagement, fostering a deeper comprehension of scientific concepts. Through the creation of virtual laboratories, students can experiment with equipment and materials akin to those in actual labs, simultaneously enhancing practical skills relevant to professional roles. These virtual labs offer intricate challenges across various domains, supplying virtual tools to simulate procedural conditions and problem-solving scenarios (Rashidovna, 2020).

The educational landscape in Ghana is marked by the ever-growing importance of science as a foundational subject that provides students with a comprehensive understanding of scientific principles across multiple disciplines. However, within the context of some Ghanaian senior high schools, as cited in (Opoku-Asare et al., 2015), a pressing concern has emerged regarding the attitudes of Visual Art students towards the learning of Integrated Science, amongst other core subjects. Despite its significance in fostering holistic scientific literacy, Visual Art students consistently exhibit disinterest in this interdisciplinary subject, indirectly affecting their academic achievements and potentially limiting their future career prospects. Reports from the study by Opoku-Asare et al., in 2015, and preliminary investiga-

tions carried out at Nkawie SHTS (where the researcher is a Visual Art facilitator) indicate that Visual Art students' performance in Integrated Science consistently falls below expectations, leading to comparisons that highlight their inferior outcomes compared to their counterparts in other programmes of study in the Senior High School. The root causes of this issue are diverse, encompassing both misconceptions about the subject's complexity and a prevailing belief that Integrated Science is reserved exclusively for science-oriented students. This misperception contributes to a skewed prioritization of academic efforts, with Visual Art students dedicating more time to elective practical exercises and less time to the mastery of Integrated Science which is an equally important subject and a determinant for further studies in most tertiary institutions in Ghana. Moreover, the existing teaching methods employed by Integrated Science teachers seem to have limited impact in bridging the gap between the subject's challenging content and Visual Art students' perceptions of its importance. Preliminary investigations into the teaching of the Integrated Science subject to Visual Art students suggest that their (Visual Art students) desire for visuals is not adequately met since Integrated Science teachers do not use visual aids in their teaching. This, in turn, makes it difficult for the Visual Art students to grasp the scientific concepts, and eventually leads to lack of engagement in the subject. This observation aligns with the assertion of Dilshoda et al., 2022, that traditional teaching of science does not often allow very active involvement of students in class. According to a number of scholars, practical experimentation holds significant importance in the realm of science education (Heradio et al., 2016; Kolil et al., 2020). Additionally, experiments serve as a valuable tool for educators in visually conveying scientific concepts to their pupils (Jones, 2018).

In light of these challenges, there is an evident need to explore innovative approaches that can effectively transform the attitudes of Visual Art students towards the learning of Integrated Science. One potential solution is the integration of virtual labs, a technological tool that offers interactive and experiential learning experiences. The need to determine the role an interactive virtual laboratory plays in education have been carried out in several studies outside the African continent – mostly centred on the effectiveness of the virtual laboratory as used by science teachers and on science students' attitude toward the study of science (Caño de las Heras et al., 2022; Dilshoda et al., 2022; Alarcon et al., 2022; Polat & Godek, 2021; Kolil et al., 2020). However, the effectiveness of virtual labs in enhancing Visual Art students' attitude toward the learning of Integrated Science

within the specific context of Africa and Ghana remains largely uncharted territory. Given the aforementioned premise, the study aimed to, first, assess the attitudes of Visual Art students toward the learning of Integrated Science at Nkawie Senior High Technical School, and to examine the effect virtual lab has on enhancing the attitudes of the participants toward the learning of Integrated Science at Nkawie Senior High Technical School. A null hypothesis was proposed for the study stating that "There is no statistically significant difference between attitudes of students who experience virtual lab instruction and those who receive conventional instruction toward the learning of Integrated Science."

Using a sequential explanatory approach and a quasi-experimental research design, as well as incorporating theoretical frameworks such as the Attitude towards Science and the Unified Theory of Acceptance and Use of Technology (UTAUT), the study shed light on the diverse nature of students' attitudes and the potential impact of technology-enhanced learning interventions. Through the comparison of pre- and post-tests scores, the initial perceptions of the students were obtained. The findings revealed that the students held a variety of attitudes towards the subject, highlighting the necessity of confronting these attitudes in educational strategies to facilitate effective learning experiences. The results of the post-test scores of the second objective revealed the extraordinary influence of the virtual lab intervention on various aspects of student attitudes. Factors such as Intellectual Accessibility, Interest and Utility, Emotional Satisfaction, Anxiety, and the Total Attitude Score on the scale adopted all improved significantly among students who participated in the virtual lab instruction. Excerpts from interviews also validated the quantitative data positively. These results demonstrate the power of technology to transform students' perspectives and enrich their educational experiences. The results strongly support the incorporation of virtual laboratories as an effective instrument for improving attitudes towards the study of Integrated Science.

However, the interpretation of the results is limited to such factors as sample size and generalizability, duration of exposure, learning context, learning context, characteristics of the control group, as well as attitude stability. Notwithstanding these limitations, the findings of the research demonstrate the potential for virtual laboratories to influence positively the attitudes of Visual Art students towards the study of Integrated Science. The observed shifts in attitudes towards greater accessibility, interest, emotional satisfaction, and decreased anxiety demonstrate the intervention's efficacy. These findings have implications for curriculum design, instructional methodologies, and the integration of educational technology to

address misconceptions about the complexity of Integrated Science by providing Visual Art students in Nkawie SHTS – and to a wider stretch of such students in Ghana – with interactive and visually engaging experiences that break down difficult concepts into more digestible components. By actively participating in virtual experiments and simulations, Visual Art students can gain a deeper understanding of scientific principles that may have seemed intimidating or abstract in traditional classroom settings.

2. Related Findings and Theoretical Framework

2.1 Virtual Lab: A Brief Description

According to Syahfitri et al. (2020), a virtual laboratory refers to a compilation of computer programmes designed to depict intricate phenomena typically encountered in traditional physical laboratory settings. According to Rohim (2020), the virtual laboratory offers pupils an optimal educational setting in which they can engage in self-paced learning. According to Bima et al. (2021), one advantage of utilizing a virtual laboratory is the ability for students to acquire knowledge about objects that are not readily observable inside the confines of a traditional classroom setting. Furthermore, a notable benefit of utilizing a virtual laboratory is the potential for learning in environments with restricted resources and infrastructure (Bima et al., 2021). Hence, (Salmerón-Manzano & Manzano-Agugliaro, 2018) posit that, the utilization of virtual laboratories proves advantageous for students as it enables them to construct and execute simulated experiments, thereby enhancing their comprehension and analysis of the phenomena under investigation inside the virtual laboratory setting.

2.2 Effectiveness of Virtual Labs

Determining the effectiveness of a teaching instrument in facilitating the attainment of targeted learning goals is a crucial area of knowledge for educators. Hence, prior to the integration of virtual laboratories, it is imperative to ascertain that these virtual labs possess the capacity to facilitate students' educational advancement and cognitive development. Researchers have conducted studies to explore the feasibility of incorporating virtual laboratories as an alternative or complementary resource to traditional face-to-face laboratory experiences, with the objective of evaluating the benefits of the virtual lab setting on students' educational attainment (Tatli & Ayas, 2013; Enneking et al., 2019). In a study conducted by Pyatt and Sims (2012), similar findings were obtained with regards to high school chemistry students. The students actively participated in a cyclical procedure that involved switching between virtual and in-person laboratory sessions. The primary objective of this process was to assess their proficiency in several skills, including data interpretation, hypothesis formation, and prediction capabilities, in both types of laboratory settings. The outcomes of this assessment indicated that there was minimal disparity in these measured competencies be-

tween the two lab modalities during one phase of experimentation. Furthermore, in a second trial, the cohort subjected to virtual laboratories exhibited an increase in their evaluation scores, indicating that virtual laboratories have the potential to function as a viable alternative to physical laboratories in terms of comprehending conceptual knowledge.

Furthermore, Davenport et al. (2018) evaluated the effectiveness of virtual labs across various contexts. In a study involving high school students, instructors were tasked with employing virtual labs in diverse ways—substitution for in-person labs, supplementation to in-person labs, and as a review tool. Students engaged with virtual labs through assignments, in-class activities, and individual or paired work. According to pre- and post-test results, students derived learning benefits from all applications of virtual labs, but the most substantial improvements in test scores occurred when the labs were employed for review purposes and when students interacted with them individually.

Despite virtual labs proving to be equally reliable as traditional labs for conveying chemistry concepts, educators aspire for students to hold a positive attitude towards the subject matter they're being taught. Examining the impact of virtual lab experiences on student attitudes and affective measures is a further aspect that requires investigation before virtual labs can be comprehensively endorsed as an effective pedagogical approach. Nevertheless, research outcomes concerning potential shifts in student attitudes when virtual labs replace physical labs remain somewhat inconclusive.

2.3 Theoretical Framework

At the heart of this theoretical exploration of assessing the attitudes of Visual Art students toward learning Integrated Science as well as enhancing these attitudes positively with the introduction of virtual labs lie the Attitude toward Science, and the Unified Theory of Acceptance and Use of Technology (UTAUT) – a framework that intricately dissects the factors underpinning individuals' adoption and utilization of technology across diverse domains.

2.4 Attitude toward Science

The theoretical framework of "Attitude Towards Science" postulates that attitudes consist of three main components: cognitive (beliefs and thoughts), affective (emotional responses), and behavioural (intentions and actions) (Osborne et al., 2003). Incorporating the Attitude Towards Science framework into this study allows for an in-depth study of how virtual laboratories influence each attitude dimension among Visual Art students. By analysing changes in cognitive beliefs, affective responses, and behavioural intentions, the research can provide a com-

prehensive evaluation of the efficacy of virtual laboratories in fostering a more positive attitude towards the study of Integrated Science. This theoretical lens is also consistent with the study's objectives of comprehending the influence of virtual laboratories on students' attitudes and can provide valuable insights into the potential mechanisms by which attitude transformation occurs.

2.5 Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT), formulated by (Venkatesh et al., 2003), offers a comprehensive framework for understanding the factors that influence individuals' intentions and behaviours when adopting and using technology. Applying the UTAUT framework to the context of virtual labs in Visual Arts education and their impact on students' attitudes toward Integrated Science can provide valuable insights. The application of the UTAUT framework provides a comprehensive lens through which to explore how virtual labs can enhance Visual Arts students' attitudes toward the study of Integrated Science. Researchers can gain an understanding of the mechanisms that influence students' acceptance of virtual labs as a tool for interdisciplinary learning by analysing the interplay of factors such as performance expectations, effort expectancy, social influence, facilitating conditions, and behavioral intention.

3. Research Methodology

3.1 Approach and Design

A mixed-methods approach was chosen for this research. As posited by McKim (2017), the growing prevalence of mixed methods research underscores the question of how the perceived worth of mixed methods research compares to a solely quantitative or qualitative inquiry. Grasping the perceived value of combining two distinct approaches is essential, particularly considering the extra resources in terms of time, finances, and expertise required to carry out a mixed methods study. The mixed methods approach, as adopted in this study, was used to engage participants in the intervention and to evaluate the outcomes of the intervention because it is a convenient method for undertaking research studies involving two or more methods used in the same research study (Wiersma & Jurs, 2009). In addition, the mixed methods approach was chosen because it allows the researcher to observe a phenomenon from a variety of perspectives in order to gain a thorough, all-encompassing understanding. There are numerous categories of mixed methods, but Terrell (2016) identified the three most common as sequential-ex-

planatory, sequential-exploratory, and convergent designs. This study further utilized a sequential explanatory design in which the quantitative phase (statistics) was collected first, followed by the qualitative phase (personal experience) (Creswell, 2013). Concerning the quantitative data, the researcher gave the sample a pre- and post-test using the Attitude toward the Subject of Chemistry Inventory (ASCI). For qualitative data collection, the researcher used interviews.

Moreover, a quasi-experimental design was adopted for the study. In quasi-experimental designs, the selection of the comparison group aims to closely match the treatment group's baseline (pre-intervention) characteristics (Hanita et al., 2017). This comparison group serves as a representation of what would have transpired without the intervention. The intervention or treatment is then administered to the experimental group. In contrast, the control group receives no treatment. In accordance with the design specifications, the researcher employed the pre-test/post-test methodology with control and experimental groups. The decision was made because it allowed the researcher to compare the experimental and control groups in greater detail. To conduct an effective study and collect data for analysis, the researcher reviewed the data collection procedure's description.

3.2 Participants and Setting

The study encompassed a cohort of fifty-one students – all students in the third-year Visual Art class at Nkawie Senior High Technical School, situated in the Atwima Nawabiagya Municipal, Ashanti Region, Ghana – who were distributed between the experimental group ($n = 26$) and the control group ($n = 25$). The division of students into the two groups was naturally occurring, mirroring the existing structure of two classes in the Visual Arts Department, namely Visual Art 1 and Visual Art 2. The study was undertaken in the second semester of the 2022/2023 academic year in the same school.

3.3 Data Collection

The instrument utilized in this research was the Attitude toward the Subject of Chemistry Inventory (ASCI), which was developed by Bauer in 2008. The ASCI was administered as a self-report questionnaire consisting of twenty items presented in a semantic differential format. Each item began with the phrase "Chemistry is..." and required participants to indicate their position on a seven-point scale that ranged from opposing adjectives. For instance, adjectives such as "challenging" versus "unchallenging" and "clear" versus "unclear" were employed. This method ensured that participants were consistently reminded of the subject of Chemistry throughout the questionnaire. The completion time for the survey was approximately ten minutes, and it was distributed to participants in the form of printed

sheets. The twenty survey items were classified into four distinct factors: Intellectual Accessibility, Interest and Utility, Emotional Satisfaction, and Anxiety. The Interest and Utility factor focused on students' perceptions of Chemistry's excitement, value, and fascination. The Anxiety aspect explored students' emotional reactions to Chemistry using descriptors such as "enjoyable," "tense," and "revolting." The Intellectual Accessibility category encompassed items that contrasted "confusing" with "clear" and "complicated." Bauer (2008) identified these factors through the systematic classification of adjectives into distinct patterns, ensuring their distinctiveness and independence. Bauer's research demonstrated that the ASCI effectively gauged student attitudes toward chemistry and exhibited validity and reliability, revealing dependability coefficients that were either in close proximity to or over the threshold of 0.7, suggesting a robust degree of internal consistency. The interview questions for this study were formulated by the researcher to complement the survey results with a more comprehensive context. In the interview sessions, participants were presented with four open-ended questions that had been carefully selected. The questions revolved around the impact of the virtual lab on students' viewpoints regarding chemistry (within the context of Integrated Science), their emotions throughout the lab experience, and any shifts in their comprehension resulting from its use.

3.3.1 Intervention Process

The research process spanned roughly two weeks, with each survey administration occurring approximately one week apart. The Attitude toward Subject of Chemistry Inventory (ASCI) – which was printed on sheets and explained verbally by the researcher. – administered to students to complete. Students were given one day to accomplish the assignment and turned it in accordingly. Two days after the initial survey, the researcher, in collaboration with a colleague facilitator (an Integrated Science teacher at Nkawie Senior High Technical School), assigned a virtual lab activity on the concentration of solutions (Acids) to the experimental group using laptops in the classroom, while the control group were taught the same content separately using the traditional lecture method. The experimental group's virtual lab was designed to be completed independently, and the activity required students to use an online simulation from VR Chem Lab to construct various solutions and begin to comprehend the concept of concentrations taught. With assistance from the collaborating Integrated Science teacher, students from the experimental group were oriented on the use of the VR ChemLab for three days, and had two days to complete the assigned lab activity. During the lab activity, students were able to pose questions, and the collaborator provided assistance

through open help periods. Each of the subsequent two days, students who had not completed the experiment after two days were reminded to do so. After the experimental group had completed the lab activity, all students (experimental and control groups) were asked to repeat the questionnaire using the same methodology as the initial survey. In order to choose participants for the interview phase of the study, a random alphabet generator was employed. Each of the twenty-six alphabets was assigned to individual students within the experimental group. Subsequently, five students were randomly chosen from the experimental group to participate in the interviews, which took place one week after the completion of the lab activity. The interviews were done by the researcher throughout a single day, with each session having an estimated duration of 10 minutes. Students were permitted to respond as many times as they wished to each of four queries. The researcher asked clarifying follow-up inquiries when necessary.



Figure 1. A section of participants in the experimental group interacting with instructions on the virtual lab

(Source: Edmund Boamah Acheampong, 2023)

The raw data was transferred to a Microsoft Excel spreadsheet for cleansing, where each response was represented numerically. The items were transposed into a separate spreadsheet using Jamovi statistical software (The jamovi project, 2022). The mean scores for each item were computed thereafter. The item averages were categorised based on the criteria and item sets mentioned before. The mean scores were calculated for each factor and individual items or item sets within the entire sample. This procedure was repeated for the subsequent administration of the survey following the conclusion of the virtual laboratory activity.

Subsequently, the data collected from the survey and interviews underwent analysis to determine whether a significant shift in student attitudes occurred before and after their engagement in the virtual laboratory activity. The mean values for each component and item set were compared using both paired t-tests and independent samples t-tests. The statistical software Jamovi was employed to calculate standard deviations and conduct the t-tests. Following a comparative assess-

ment of the attitudinal scores for each factor, an investigation was conducted to identify any noteworthy alterations in the mean values. The outcomes were then presented in tabular form, illustrating the changes in average scores and highlighting statistically significant variations in the mean values.

In order to provide additional context for the quantitative survey results, the interview responses were meticulously analysed to identify discernible patterns. The researcher thoroughly reviewed the interview transcripts to identify recurring thematic patterns. Subsequently, the transcripts were further scrutinized to identify instances where these themes emerged throughout the interview process. The researcher then conducted a comparative analysis to establish a relationship between the thematic patterns identified in the interviews and the corresponding fluctuations in attitude scores exhibited by the same students. By comparing the interview responses with the attitudinal ratings, potential associations between the information conveyed during the interviews and subsequent changes in attitude scores, whether positive, negative, or neutral, were identified.

4. Findings and Discussion

4.1 Research Objective One (1)

The quantitative findings displayed in Table 1 below provide insight into the perspectives of Visual Art students on the learning of Integrated Science knowledge at Nkawie Senior High Technical School. The analysis of pre-test scores of the Control and Experimental Groups using independent samples t-tests yields significant findings that offer vital insights into the early attitudes of the students involved.

The analysis of the Intellectual Accessibility dimension using the Student's t-test reveals that there is no statistically significant distinction between the pre-test scores of the Control and Experimental Groups ($t(49) = 0.277$, $p = 0.783$). This implies that initially, there is no notable discrepancy in the intellectual accessibility attitude between the two groups. The mean difference between the two variables was found to be 0.392, while the standard error of difference was calculated to be 1.42.

The results obtained from the analysis of the Interest and Utility dimension reveal a lack of statistical significance ($t(49) = -0.844$, $p = 0.403$). This implies that the initial attitudes of both the Control and Experimental Groups are similar in terms of

their level of interest and perceived usefulness. The calculated mean difference of -1.371, along with the standard error of difference of 1.62, provide valuable information regarding the magnitude of the non-significant difference observed.

The analysis of the Emotional Satisfaction dimension using the Student's t-test indicates that there is no statistically significant difference ($t(49) = -1.703$, $p = 0.095$) between the two groups. This finding suggests that, prior to the intervention, there was no statistically significant difference in attitudes pertaining to emotional satisfaction between the Control and Experimental Groups. Additional context can be derived from the mean difference of -1.995 and the standard error of difference of 1.17.

The findings pertaining to the Anxiety dimension indicate that there is no statistically significant distinction ($t(49) = 0.790$, $p = 0.433$) in the pre-test ratings observed between the groups. This finding indicates that the initial attitudes towards anxiousness are comparable among both the Control and Experimental Groups. The calculation of the mean difference of 0.871 and the determination of the standard error of difference of 1.10 are important factors in comprehending this particular conclusion.

In summary, the preliminary attitudes of Visual Art students towards the acquisition of Integrated Science knowledge at Nkawie Senior High Technical School, as assessed through pre-test scores, do not demonstrate substantial differences between the Control and Experimental Groups. This implies that, at the commencement of the study, both cohorts exhibited comparable levels of Intellectual Accessibility, Interest and Utility, Emotional Satisfaction, and Anxiety.

The aforementioned findings offer a foundational comprehension of the attitudes prior to the implementation of any interventions. The lack of statistically significant differences observed across multiple variables suggests that any subsequent changes in attitudes detected after the intervention may be attributable to the experimental factors rather than pre-existing disparities.

Table 1. Independent Samples T-Test: Pre-Test Scores of the Control and Experimental Groups

		Statistic	df	p	Mean difference	SE difference
Intellectual Accessibility	Student's t	0.277	49.0	0.783	0.392	0.392
Interest and Utility	Student's t	-0.844	49.0	0.403	-1.371	1.62
Emotional Satisfaction	Student's t	-1.703	49.0	0.095	-1.995	1.17
Anxiety	Student's t	0.790	49.0	0.433	0.871	1.10
Total Attitudinal Score	Student's t	-0.541	49.0	0.591	-2.103	3.89

(Source: Edmund Boamah Acheampong, 2023)

4.2 Research Objective Two (2)

The second objective of this study was to investigate the impact of virtual laboratories on the attitudes of Visual Art students towards the study of Integrated Science. The results from the post-test scores of both the Control and Experimental Groups, as seen in Table 2, provide valuable insights into the impact of the virtual lab intervention on various aspects of students' attitudes.

The post-test scores reveal a statistically significant improvement in the Experimental Group's Intellectual Accessibility dimension. The t-statistic for the student's t-test was 9.39 (df = 49, p .001). The mean difference of 10.32 indicates a substantial increase in the perception of intellectual accessibility among students exposed to the virtual lab. This enhancement suggests that the virtual lab intervention had a positive impact on students' perceptions of their grasp and comprehension of Integrated Science concepts.

The Experimental Group also demonstrated a significant improvement in the Interest and Utility dimension. The t-test resulted in a t-statistic of 2.87 (df = 49, p = 0.006), indicating that the virtual lab intervention had a positive effect on students' interest in and perception of the usefulness of Integrated Science. The mean dif-

ference of 3.17 indicates that students who were exposed to the virtual lab reported increased subject engagement and relevance.

Additionally, the Emotional Satisfaction dimension demonstrated a statistically significant improvement. The t-test resulted in a t-statistic of 4.35 ($df = 49$, $p .001$), indicating that the virtual lab intervention positively impacted students' affective satisfaction with Integrated Science learning. The mean difference of 3.34 indicates that students' affective engagement and enjoyment of the subject have increased significantly.

Following the virtual lab intervention, there was also a significant reduction in anxiety levels among Visual Art students. The t-test resulted in a high t-statistic of 15.49 ($df = 49$, $p .001$), indicating that the intervention had a substantial impact on reducing students' apprehension levels in relation to learning Integrated Science. The mean difference of 14.57 indicates a substantial decrease in apprehension, most likely attributable to the interactive and engaging nature of the virtual lab.

The Total Attitudinal Score dimension also demonstrated a significant improvement in attitudes. The t-test resulted in a t-statistic of 11.99 ($df = 49$, $p .001$), indicating that the virtual lab intervention had an overall positive effect on students' attitudes towards learning Integrated Science. The significant mean difference of 31.40 indicates that the Experimental Group's attitudes have undergone a profound shift.

In conclusion, the findings provide strong evidence that the introduction of virtual laboratories had a substantial and positive effect on the attitudes of Visual Art students towards learning Integrated Science. The enhancements in intellectual accessibility, interest and utility, emotional satisfaction, and anxiety reduction indicate that the virtual lab intervention improved students' attitudes and interest in the subject as a whole. These findings demonstrate the capacity of technology-enhanced learning aids to influence positively the attitudes and experiences of students in education.

Table 2. Independent Samples T-Test: Post-Test Scores of the Control and Experimental Groups

		Statistic	df	p	Mean difference	SE difference
Intellectual Accessibility	Student's t	9.39	49.0	< .001	10.32	1.099
Interest and Utility	Student's t	2.87	49.0	0.006	3.17	1.108
Emotional Satisfaction	Student's t	4.35	49.0	< .001	3.34	0.768
Anxiety	Student's t	15.49	49.0	< .001	14.57	0.941
Total Attitudinal Score	Student's t	11.99	49.0	< .001	31.40	2.620

(Source: Edmund Boamah Acheampong, 2023)

To gain a deeper understanding of the effect of virtual laboratories on the attitudes of Visual Art students towards learning Integrated Science, in-depth interviews were conducted with a sample of Experimental Group students – 5 students precisely. Some of the interview excerpts below offer first-hand accounts of the effects of the virtual lab intervention on various aspects of students' attitudes:

Student E (Intellectual Accessibility): "The virtual lab enhanced my understanding of science. Previously, certain concepts seemed abstract, but with the virtual lab, I could see how things actually functioned. It made difficult concepts more understandable. I felt as though I was learning by doing, which made it simpler to comprehend."

Student G (Interest and Utility): "The virtual laboratory made science engaging and practical for me. I used to find it tedious, but the simulations made it interesting. I could conduct experiments and observe real-time results. It piqued my interest in science, which I had not previously felt."

These interview excerpts demonstrate the positive impact the virtual lab intervention had on the Experimental Group's attitudes towards learning Integrated Science. Students consistently reported enhanced accessibility to scientific concepts, increased interest and utility, enhanced emotional satisfaction, decreased anxiety, and an overall more positive attitude. These firsthand accounts are consistent with the quantitative findings, highlighting the positive multidimensional influence of the virtual lab on students' attitudes.

5. Conclusion and Further Research

The objectives of the research was to assess Visual Art students' attitude toward learning Integrated Science and to examine the impact of incorporating virtual laboratories as a pedagogical tool on the attitudes of Visual Art students towards the learning of Integrated Science knowledge at Nkawie Senior High Technical School. The Attitude towards Science framework and the Unified Theory of Acceptance and Use of Technology (UTAUT) supported this study. The Attitude towards Science framework provided insights into the cognitive and affective aspects of students' attitudes towards science, whereas the UTAUT framework contributed to an understanding of how the acceptance and use of virtual laboratories could influence students' attitudes. Pre-test and post-test data were collected from both the Control and Experimental Groups, and the results provide valuable insights into the impact of the intervention on students' attitudes. The findings demonstrate the potential for virtual laboratories to influence positively the attitudes of Visual Art students towards the study of Integrated Science. The observed shifts in attitudes towards greater accessibility, interest, emotional satisfaction, and decreased anxiety demonstrate the intervention's efficacy. These findings have implications for curriculum design, instructional methodologies, and the integration of educational technology to address misconceptions about the complexity of Integrated Science by providing Visual Art students with interactive and visually engaging experiences that break down difficult concepts into more digestible components. By actively participating in virtual experiments and simulations, students can gain a deeper understanding of scientific principles that may have seemed intimidating or abstract in traditional classroom settings.

However, it is recommended that longitudinal studies be conducted to evaluate the long-term viability of the positive attitudes observed in the Experimental Group, including Visual Arts students. This would shed light on whether the shifts in students' attitudes are temporary or contribute to lasting changes in their perspectives.

6. Acknowledgement

Due credit goes to Prof. Harry Barton Essel, who supervised this research keenly, and to my colleagues – Juliet Appiah-Kubi, Griselda Besiwaa Osafo Acquaah, Regina Agbomson, Prosper Setsoafia, Russell Amoah Konadu, George Attah Aboagye, Charles Atta Koduah, Albert Koomson – who supported in diverse ways.

Alarcon, J. L. P., Dumagan, N. P., Lumakang, M. A. & Nuezca, A. P. (2022), 'Students' Attitude and Their Learning Environment in Virtual Laboratory Class.' International Journal of Applied Science

and Research, July, 5(4), pp. 85-86.

Bima, M., Saputro, H. & Efendy, A. (2021), 'Virtual Laboratory to Support a Practical Learning of Micro Power Generation in Indonesian Vocational High Schools.' Open Engineering, 11(1), pp. 508-

518.

Caño de las Heras, S. et al. (2022), 'From Paper to web: Students as partners for virtual laboratories

in Bio(chemical) engineering education.' Frontiers in Chemical Engineering, p. 1.

Creswell, J. W. (2013), 'Research Design: Qualitative, Quantitative, and Mixed Methods

Approaches.' 4th ed. London: SAGE Publications, Inc.

Davenport, J. L., Rafferty, A. N. & Yaron, D. J. (2018), 'Whether and how authentic contexts using

a virtual chemistry lab support learning.' Journal of Chemical Education, 95(8), pp. 1250-1259.

Dilshoda, S., Ruslan, K. & Dilafruz, M. (2022), 'The Effectiveness of a Virtual Laboratory in

Teaching Chemistry.' Web of Scientist: International Scientific Research Journal, 3(3), pp. 466-471.

Enneking, K. M. et al. (2019), 'The evaluation of a hybrid, general chemistry laboratory curriculum: impact on students' cognitive, affective, and psychomotor learning.' Journal of Chemical Education,

96(6), pp. 1058-1067.

Heradio, R. et al. (2016), 'Virtual and remote labs in education: A bibliometric anal-

ysis. Computers

& Education, Volume 98, pp. 14-38.

Jones, N. (2018), 'Simulated labs are booming'. Springer Nature, 562(7725), p. S5.

Kolil, V. K., Muthupalani, S. & Achuthan, K. (2020) 'Virtual experimental platforms in chemistry laboratory education and its impact on experimental self-efficacy.' International Journal of

Educational Technology in Higher Education, pp. 1-22.

McKim, C. A. (2017), 'The Value of Mixed Methods Research: A Mixed Methods Study'. Journal

of Mixed Methods Research, 11(2), p. 202-222.

Opoku-Asare, N. A. A., Essel, H. B. & Tachie-Menson, A. (2015), 'Perceptions, Attitudes and Institutional Factors that Influence Academic Performance of Visual Arts Students in Ghana's Senior

High School Core Curriculum Subjects. Journal of Education and Practice.

Osborne, J., Simon, S. & Collins, S. (2003), 'Attitudes towards science: A review of the literature

and its implications.' International Journal of Science Education, 25(9), pp. 1049-1079.

Piaget, J. (1978), 'What is psychology?'. American Psychological Association.

Polat, D. & Godek, Y. (2021)' 'PhET Interactive Simulations: Virtual laboratory Use in Science Teaching'. Ankara, MAKU, pp. 143-144.

Rashidovna, M. (2020), 'Virtual laboratories in teaching and education.' Science Index.

Salmerón-Manzano, E. & Manzano-Agugliaro, F. (2018), 'The higher education sustainability through virtual laboratories: The Spanish University as case of study.' Sustainability (Switzerland),

10(11).

Shambare, B., Simuja, C. & Olayinka, T. A., (2022), 'Understanding the Enabling And Constraining Factors In Using The Virtual Lab.' International Journal of Information and Communication

Technology Education, 1(18), pp. 1-15.

Syahfitri, F. et al. (2020), 'The Development of Problem Based Virtual Laboratory

Media to Improve Science Process Skills of Students in Biology.' International Journal of Research &

Review, 6(6), pp. 64-74.

Tatli, Z. & Ayas, A. (2013), 'Effect of a virtual chemistry laboratory on students' achievement.'

Journal of Educational Technology & Society, 16(1), p. 159-170.

Terrell, S. R. (2016), 'Writing a Proposal for Your Dissertation: Guidelines and Examples.' New

York: The Guilford Press.

The jamovi project. (2022), jamovi. (Version 2.3) [Computer Software]

Venkatesh, V., Morris, M. G., Davis, G. B. & Davis, F. D., (2003), 'User Acceptance of Information Technology: Toward a Unified View. MIS Quarterly, 27(3), pp. 479-501.

Wiersma, W. & Jurs, S. G. (2009), 'Research methods in education: an introduction.' 9th ed. Boston: Pearson.

Expanding Access In The Digital Age Through Inclusive And Adaptive E-Learning: A Case Study Of The BUSE PGDHE Block Release Programme

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ABSTRACT:

The rapid expansion of digital technologies in higher education has created new opportunities for learning but also deepened access inequalities, particularly in resource-constrained settings such as rural Zimbabwe. This qualitative case study explores how the Bindura University of Science Education (BUSE) Postgraduate Diploma in Higher Education (PGDHE) block release programme employed a multi-modal, inclusive e-learning strategy to bridge these divides in a PHE508 – Elearning in Higher Education Course. Leveraging a blend of synchronous (Zoom we conferencing +Zoom AI Companion), asynchronous (MyBUSE LMS), and mobile-based (WhatsApp) platforms alongside AI-supported reflective tools (Riffbot), the course addresses infrastructural limitations while fostering learner engagement and professional identity development. Data collected from LMS logs, WhatsApp interactions, Zoom sessions, and AI transcription and reflection journals reveal that low-cost technologies can effectively scaffold peer collaboration, digital literacy, and metacognitive reflection. The study highlights the transformative potential of integrating accessible technologies and AI-driven notetaking and reflection in teacher education programmes within resource constrained environments such as the developing context. Implications for policy, pedagogy, and further research into scalable, contextually responsive digital learning models are discussed.

KEYWORDS: E-learning, Artificial Intelligence, Digital Divide, Inclusive Education

1. Introduction

The global rise of digital learning platforms has been heralded as a revolution in higher education, opening up unprecedented opportunities for access, personalisation, and scalability (UNESCO, 2023). However, this digital promise is not evenly distributed. In regions like sub-Saharan Africa particularly in rural parts of Zimbabwe, learners face persistent structural and infrastructural barriers that limit their participation in the digital learning economy (Chigona & Mbhele, 2021; ITU, 2023). These include limited internet access, affordability of devices, and lack of digital literacy. Consequently, while e-learning expands in principle, in practice, it often deepens existing divides unless deliberate inclusive strategies are implemented.

This study investigates how a public university in Zimbabwe, Bindura University of Science Education (BUSE), has sought to bridge this digital divide through the innovative deployment of inclusive, low-cost, and adaptive technologies in its Postgraduate Diploma in Higher Education (PGDHE) programme PHE508 – e-Learning in Higher Education course. The PGDHE is delivered in a block release format, catering primarily to in-service educators spread across all ten provinces of Zimbabwe. These students often reside in rural or peri-urban areas and have limited face-to-face interaction with lecturers. This challenge is further intensified by infrastructural limitations such as inconsistent power supply, low bandwidth, and a scarcity of digital devices.

To alleviate these constraints, BUSE implemented a multi-modal, technology-integrated strategy combining high- and low-end tech tools such as Zoom, Google Classroom, the MyBUSE LMS, and most importantly WhatsApp, a low spec, widely accessible and user-friendly mobile messaging application. WhatsApp has proven particularly effective in sustaining student engagement, facilitating peer collaboration, and scaffolding learning in asynchronous and synchronous formats (Mukabeta, Tunjera & Magomelo, 2013). Additionally, the course piloted the integration of AI-supported tools, notably Zoom's AI Companion for transcription and note-taking, as well as Riffbot, which enabled reflective journaling and self-regulated learning critical for developing professional teaching identities.

The aim of this study is to assess how inclusive, adaptive e-learning technologies especially WhatsApp and AI-based tools have been deployed to bridge access gaps, support reflective practice, and enhance digital literacy within the BUSE PHE508 block release course. Specifically, the study seeks to:

- Explore the pedagogical value of WhatsApp-supported e-learning as a tool for peer scaffolding and communication.

- Evaluate the impact of AI-driven reflection tools, such as Riffbot, on students' professional development and self-directed learning.
- Analyze how multi-modal learning environments adapt to infrastructural limitations in low-resource settings.

The research adopts a qualitative case study methodology (Yin, 2018), analyzing evidence from LMS interaction logs, Zoom/WhatsApp conversations, video/audio submissions, and AI-generated transcripts and reflection outputs. The study contributes to closing a critical research gap: while much has been written about high-tech solutions in education, there is limited empirical work focusing on how low-tech tools and lightweight AI solutions can meaningfully support inclusive teacher education in the Global South, particularly in postcolonial, resource-limited contexts.

By examining the PGDHE programme's strategic use of simple yet effective technologies in the PHE508 course, this study aims to reimagine digital learning as a spectrum where adaptability, inclusivity, and contextual relevance are more important than technological sophistication. The findings are intended to inform resource constrained environments.

2. Literature Review

The implementation of inclusive and adaptive e-learning in Zimbabwean higher education cannot be understood in isolation from the broader social, technological, and pedagogical ecosystem that shapes learner experiences. This section situates the BUSE PGDHE programme within key contextual realities and theoretical frameworks, offering the lens through which this case study is both designed and analyzed.

2.1 The Zimbabwean Higher Education Context

Zimbabwe's tertiary education system is characterised by a growing commitment to digitalisation (Zimbabwe Ministry of Higher and Tertiary Education, 2022), yet persistent inequalities in infrastructure and access continue to constrain full participation. Rural areas in particular suffer from unstable electricity, intermittent internet access, high data costs, and low digital literacy levels among both students and educators (Chigona & Mbhele, 2021; ITU, 2023). These factors necessitate pedagogical approaches and technologies that are not only cost-effective and scalable but also inclusive and flexible.

The BUSE PGDHE programme, aimed at developing the pedagogical competencies of higher education lecturers, must therefore operate at the intersection

of policy aspirations and lived technological constraints. The institution's digital learning strategy reflects a pragmatic blend of high-end platforms (Zoom, LMS) and low-end, accessible tools like WhatsApp, audio messages, and offline PDFs resources that reflect the material realities of most students' environments.

2.2 Theoretical Frameworks for Inclusion and Access

At the heart of this study is the concept of inclusive education, which is informed by the Universal Design for Learning (UDL) framework (CAST, 2018). UDL emphasizes multiple means of representation, engagement, and expression principles that are operationalized in the PGDHE programme through varied instructional formats such as video lectures, voice notes, synchronous Zoom discussions, WhatsApp group interactions, and text-based resources on the LMS. This multi-modal approach ensures that learners with different abilities, access levels, and learning preferences are not left behind. By creating time- and device-flexible learning pathways, the programme supports the participation of educators working full-time across Zimbabwe, allowing them to engage asynchronously when necessary.

2.3 The Digital Divide Model

The programme's use of technology is further analyzed using van Dijk's (2020) model of the Digital Divide, which outlines a three-tier structure of exclusion:

1. Access divide (physical access to devices and internet),
2. Skills divide (digital and information literacy), and
3. Usage divide (ability to use ICT meaningfully).

BUSE's strategy addresses these divides by choosing tools like WhatsApp that most students already access for personal use, lowering the threshold for entry. Content compression (e.g., reduced video sizes), voice notes, and simplified interfaces aim to reduce both access and skills gaps. WhatsApp becomes a pedagogical equaliser, enabling peer learning and supporting distributed scaffolding even when more sophisticated systems fail.

2.4 Learning Theories: Connectivism and Scaffolding

The pedagogical strategy of the PGDHE programme is grounded in constructivist learning theories, particularly Vygotsky's (1978) notion of social scaffolding, where learners build knowledge through guided interaction with peers and more knowledgeable others. WhatsApp groups facilitate this peer-to-peer support, transforming informal digital spaces into dynamic learning environments. In addition, Siemens' (2005) Connectivism is highly relevant to the programme's distributed digital model. Connectivism conceptualises learning as occurring across a network of people, technologies, and resources, emphasizing just-in-time learning and learner autonomy. WhatsApp enables fluid knowledge exchange, while the MyBUSE LMS serves as a repository of structured materials, and AI tools like Riffbot act as metacognitive scaffolds.

2.5 Social Media-Enabled and Mobile Pedagogies

Emerging African scholarship (Mukabeta et al., 2013; Chawinga, 2017) has underscored the role of mobile and social media platforms in creating alternative pedagogical spaces in under-resourced environments. WhatsApp has been used in previous teacher education initiatives to boost interaction, motivation, and peer learning. In the PGDHE case, WhatsApp not only facilitates communication and accountability but also supports co-construction of knowledge, immediate feedback, and peer-led tool testing. Mukabeta's (2014) analysis of podcasts as a scaffolding tool complements this strategy by highlighting the value of audio learning in low-bandwidth environments. Podcasts and voice notes allow for asynchronous participation without excluding those with limited literacy or connectivity.

2.6 Artificial Intelligence in Reflective Practice

The programme also experiments with AI-driven tools for reflective practice, notably Riffbot, which is designed to prompt, record, and analyze metacognitive reflections. Grounded in the reflective learning frameworks discussed by Nguyen et al. (2023) and Holmes et al. (2022), Riffbot's use marks a novel frontier in digital teacher education. Rather than merely automating feedback, Riffbot fosters structured reflection, enabling students to articulate evolving pedagogical identities and gain insight into their teaching philosophies. These tools bridge the skills and usage divides by supporting learners in developing self-regulation, critical thinking, and reflective habits, even in the absence of synchronous human feedback. In resource-limited settings where instructor capacity may be constrained,

such AI agents offer promising support for scalable personalised learning.

3. Research Methodology

This study adopts a qualitative case study design to explore how the BUSE PGD-HE block release programme operationalises inclusive and adaptive e-learning in a low-resource, digitally divided context. The methodology is informed by the need to capture context-rich, experiential, and multi-perspective data from real-world educational settings where multiple technologies, both high- and low-end are in use. A case study is appropriate for this investigation because it allows for an in-depth, holistic understanding of complex phenomena within their real-life context (Yin, 2018).

3.1 Case Study Design

The research is framed as an exploratory and explanatory single case study centered on the 2025 cohort of the PGDHE programme at Bindura University of Science Education (BUSE). This cohort is composed of adult learners who are practicing lecturers enrolled in the postgraduate diploma programme as part of professionalisation efforts mandated by Zimbabwe's higher education reforms. The block release model, which blends face-to-face sessions with sustained on-line interaction, provides a unique opportunity to study how learners navigate, negotiate, and adapt to digital learning environments over time, especially when access is uneven.

The case study investigates multiple components of the programme, including:

- Instructional technologies used (e.g., LMS, Zoom, WhatsApp, podcasts, AI tools)
- Pedagogical strategies for inclusion and reflection
- Student engagement, collaboration, and digital skill development
- Reflections on professional identity formation

3.2 Data Sources

To understand these dynamics, the study triangulated data from multiple sources to ensure credibility, validity, and depth of interpretation. The key data sources included:

MyBUSE LMS logs and submissions: These provided evidence of student participation, frequency of access, and types of content engagement (e.g., reading materials, quizzes, assignment uploads).

WhatsApp group chats and voice notes: These were used to trace patterns of peer interaction, real-time support, collaborative problem-solving, and social learning. Ethical clearance was obtained to analyse these digital interactions, and participants were anonymised.

Zoom session recordings and attendance reports: These captured synchronous engagement, lecture delivery styles, and student-instructor interaction.

Podcasts and audio files submitted by students: These revealed learner agency in producing content, especially in instances where bandwidth was a barrier.

Riffbot-generated reflective journal entries: The AI tool was integrated into the course to support reflective practice. These entries provided insight into learner metacognition, professional growth, and identity formation.

Instructor field notes and course documentation: These provided contextual detail and curriculum intent from the instructional team's perspective.

3.3 Sampling

A purposive sampling strategy was employed to select data sources and participants that were most relevant to the research questions. Ten PGDHE students were selected for deeper qualitative analysis based on:

- Regular participation in WhatsApp and Zoom sessions,
- Engagement with Riffbot reflections, and
- Availability of audio submissions or LMS activity logs.

This sample offered a diverse representation across different Zimbabwean provinces, ensuring geographic spread, connectivity variance, and diverse institutional affiliations.

3.4 Data Analysis

Data was analysed using a thematic analysis approach (Braun & Clarke, 2006), guided by both deductive codes drawn from the theoretical framework (e.g., inclusion, scaffolding, digital divide, AI reflection) and inductive codes that emerged from the data (e.g., tool appropriation, workaround strategies, digital peer mentorship).

The analysis process involved:

1. Familiarisation with data: Reading transcripts, WhatsApp logs, and journal entries to understand general trends.
2. Coding: Using NVivo software to tag patterns across media (e.g., instances of low-tech adaptation, reflective insights, collaboration).
3. Theme development: Grouping codes into overarching themes such as "WhatsApp as a pedagogical space," "low-bandwidth innovation," and "AI-mediated identity reflection."
4. Interpretation: Connecting the themes to the research questions and contextual realities, with constant reference to UDL, Connectivism, and the Digital Divide model.

Special attention was given to multi-modal triangulation comparing patterns across platforms (e.g., comparing LMS engagement with WhatsApp activity) to validate or deepen findings. This was crucial in identifying the compensatory role that low-end tools like WhatsApp and audio messages played when other platforms were inaccessible.

3.5 Ethical Considerations

Ethical approval was obtained through the university's Research Ethics Committee. Participation in the reflective AI tool was voluntary, with clear disclosure on data use. All data were anonymised, and participants were assigned pseudonyms. Due to the personal and private nature of WhatsApp conversations, participants in the focal groups were explicitly asked for consent to analyse and quote messages in anonymised form.

4. Findings and Discussion

The analysis of data from the BUSE PGDHE block release programme reveals a rich, layered picture of how inclusive and adaptive e-learning can be implemented in low-resource, high-diversity contexts. The findings are grouped into six thematic areas aligned with the research questions and theoretical constructs: multi-modal delivery, low-end technology use, AI-supported reflection, peer collaboration, challenges and mitigation strategies, and student learning outcomes.

4.1 Multi Modal Inclusive Delivery

The BUSE PGDHE programme employed a multi-modal delivery strategy that blended formal and informal platforms including Zoom, Google Classroom, My-BUSE LMS, and WhatsApp to support a wide range of learning styles and access capabilities. This approach resonates strongly with the Universal Design for Learning (UDL) framework (CAST, 2018), ensuring multiple means of representation and expression. Participants noted that while the LMS hosted structured content, it was WhatsApp that became the most responsive and interactive platform, especially in periods between Zoom sessions. For example, lecture materials uploaded to the LMS were often complemented by WhatsApp summaries, clarifying questions, and peer-to-peer discussions. This not only reinforced understanding but also cultivated a culture of distributed instruction, with students acting as co-educators. This hybrid model allowed the programme to remain resilient to infrastructural inconsistencies for example where some learners had connection difficulties or got dropped due to bandwidth issues during Zoom live sessions, text based AI generated transcriptions would be shared after the lecture as well as links to recorded videos. Audio summaries would be made and text summaries on WhatsApp, ensuring continuity.

4.2 Low-End Technology for Engagement

WhatsApp was identified as the cornerstone of inclusive access, particularly in rural and peri-urban areas. It facilitated asynchronous and synchronous learning, offered low data consumption, and allowed easy sharing of multiple media formats i.e. text, voice, images, and videos. These characteristics made WhatsApp not just a communication tool, but a pedagogical space (Mukabeta et al., 2013; Chawinga, 2017). Students regularly shared audio reflections, mini-podcasts, and summaries via voice notes. These audio formats compensated for low literacy levels or screen fatigue, particularly during peak teaching periods. This aligns with Mukabeta's

(2014) findings on podcasting as a scaffolding tool in African higher education. Additionally, the instructional team made a conscious effort to compress videos and slide decks before upload, enabling learners with limited bandwidth to download and engage with materials offline. These practices reflect a pragmatic response to the access and usage gaps highlighted in van Dijk's (2020) digital divide model.

4.3 AI Driven Reflective Practice

A novel component of the programme was the integration of Riffbot, an AI-powered reflection chatbot that prompted students to journal their learning experiences and evolving pedagogical beliefs. This tool was introduced to foster structured reflection, self-regulation, and professional identity formation.

- Analysis of the Riffbot logs revealed:
- An increased frequency of self-reflective entries after each block module;
- Emergence of meta-awareness in teaching philosophies (e.g., shifts from content delivery to student-centered approaches);
- Use of AI prompts as starting points for deeper conversation in WhatsApp groups.

Students expressed initial discomfort with the AI's "robotic" tone but later adapted to its non-judgmental and always-available nature, which encouraged honest reflections. This aligns with studies by Nguyen et al. (2023) and Holmes et al. (2022) on the capacity of AI tools to support metacognitive and affective dimensions of learning, especially when instructor feedback is delayed or limited.

4.4 Peer Collaboration and Tool Testing

Peer learning and collaboration flourished primarily through WhatsApp groups. Students reported using the platform not only for discussions but for testing new digital tools, such as Padlet, Canva, and podcast apps. These tools were often discovered by one or two students and then shared and explained to others through voice notes, screenshots, or short tutorials. This grassroots, exploratory behavior exemplifies connectivist learning theory (Siemens, 2005), where knowledge is distributed across networks and learning occurs through interaction and openness to new information. The WhatsApp environment allowed for horizontal learning structures, where both experienced and novice users could contribute without hierarchical barriers. Such tool-testing activities also demonstrated pedagogical

innovation, as students began to mirror the facilitators' use of technology in their own institutions. In this way, WhatsApp functioned as an incubator for digital pedagogical practice.

4.5 Addressing Challenges: Connectivity, Devices & Platform Redundancy

While the multi-modal strategy enabled wide participation, several challenges persisted:

- Poor network coverage during Zoom sessions, especially in rural provinces like Matabeleland North and Mashonaland West;
- Limited access to laptops, with many students relying solely on smartphones;
- Intermittent electricity supply, affecting synchronous learning sessions.

The programme's adaptive response included:

- Redundancy across platforms: The same material was posted on Zoom, LMS, and WhatsApp to ensure no learner was left behind.
- Encouraging audio responses over typed assignments for students with typing limitations or poor internet.
- Offline-first strategies, such as allowing downloads of all course materials for offline review.

These adaptations align with global guidelines for digital inclusion in low-income contexts (ITU, 2023), and they underscore the importance of flexibility and redundancy in instructional design.

4.6 Student Outcomes: Digital Literacy and Professional Identity

One of the most significant outcomes was the observed growth in digital literacy. By the end of the programme, most students reported confidence in:

- Navigating and uploading content to LMS platforms;
- Hosting and moderating Zoom sessions;
- Using basic AI tools for reflection and planning.

In addition, analysis of Riffbot reflections and end-of-programme evaluations indicated a clear shift in pedagogical identity. Many participants expressed a move from "chalk and talk" methods toward interactive, learner-centered teaching models, driven by exposure to blended pedagogies and mobile technologies. This outcome suggests that the programme not only equipped students with technical competencies but also reshaped their teaching philosophies, preparing them to act as digital change agents within their institutions.

5. Conclusion and Further Research

This case study of the BUSE PGDHE block release programme demonstrates that inclusive and adaptive e-learning strategies anchored in low-cost, accessible technologies can effectively bridge digital divides in resource-constrained higher education settings. By leveraging a multi-modal approach combining the strengths of formal LMS platforms, synchronous tools like Zoom, and ubiquitous mobile messaging applications such as WhatsApp, the programme successfully addressed key barriers related to infrastructure, access, and learner engagement.

The integration of AI-powered reflective tools like Riffbot marked an innovative step forward, illustrating how metacognitive scaffolding can be operationalised at scale to support professional identity formation and self-regulated learning. Importantly, the AI component complemented rather than replaced human facilitation, offering a non-threatening, consistent prompt for reflection in contexts where instructor feedback may be delayed or limited.

The study affirms the vital role of low-end, widely accessible technologies in fostering pedagogical innovation and inclusion, especially in sub-Saharan African contexts where broadband connectivity and device access remain uneven. WhatsApp, in particular, emerged as a powerful pedagogical space enabling peer collaboration, scaffolded learning, and tool appropriation that extended well beyond formal instruction.

These findings have practical implications for policy-makers, educators, and instructional designers aiming to expand quality higher education access in low- and middle-income countries (LMICs). They underscore the necessity of contextualised, learner-centered designs that prioritize flexibility, redundancy, and multiple pathways to engagement over reliance on high-end technologies alone.

5.1 Directions for Further Research

While this study provides foundational insights, several avenues warrant further investigation:

- **Longitudinal Studies:** Tracking graduates over time to evaluate how digital literacy and pedagogical shifts translate into classroom practice and institutional change.
- **Broader AI Tool Integration:** Exploring the potential of diverse AI applications beyond reflection bots for formative assessment, personalised learning, and automated feedback within teacher education.
- **Scalability and Sustainability:** Assessing how the BUSE model can be adapt-

ed and scaled to other programmes and institutions in Zimbabwe and similar LMIC contexts, including cost-benefit analyses.

- **Learner Diversity and Inclusion:** Deepening exploration of how learners with disabilities, varied linguistic backgrounds, and differing socio-economic statuses experience and navigate such multi-modal e-learning ecosystems.
- **Faculty Development and Support:** Investigating the training and capacity-building needs of instructors to effectively facilitate blended, AI-augmented learning environments.

The BUSE PGDHE block release programme offers a replicable and contextually grounded blueprint for expanding equitable higher education access in the digital age. By embracing inclusive technologies and reflective practice, the programme not only empowers individual learners but also contributes to the transformation of educational systems toward greater accessibility and relevance.

6. References

Bozkurt, A., Karadeniz, Ş., & Dörtkardeş, M. (2020). Flexible MOOCs and inclusive education: Implications for equity and access. *International Journal of Educational Technology in Higher Education*, 17(1), 45–62. <https://doi.org/10.1186/s41239-020-00213-0>

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp063oa>

CAST. (2018). Universal Design for Learning guidelines version 2.2. Retrieved from <http://udlguidelines.cast.org>

Chawinga, W. D. (2017). Using WhatsApp and Facebook online social groups for teaching and learning in higher education: A case of Malawi. *International Journal of Education and Development Using Information and Communication Technology*, 13(2), 4–21.

Chigona, A., & Mbhele, N. (2021). Exploring digital inequality and its impact on online learning in rural Zimbabwe. *Journal of Education and Information Technologies*, 26(4), 4955–4973. <https://doi.org/10.1007/s10639-021-10520-7>

Holmes, W., Bialik, M., & Fadel, C. (2022). Artificial Intelligence in education: Promises and implications for teaching and learning. Center for Curriculum Redesign.

International Telecommunication Union (ITU). (2023). Measuring digital development: Facts and figures 2023. Geneva, Switzerland: ITU. <https://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>

- Mukabeta, T. (2014). Using activity theory to analyse the use of podcasts to facilitate scaffolding in a higher education setting. *Journal of Educational Technology in Curriculum and Instruction Studies (JETCIS)*, 5(2), 45–60. Retrieved from <https://www.buse.ac.zw>
- Mukabeta, T., Tunjera, N., & Magomelo, M. (2013). Increasing interaction by integrating SMS into the VODL teacher education programme: A case of Bindura University. *Greener Journal of Educational Research*, 3(4), 191–199.
- Nguyen, T., Zafar, A., & Liu, L. (2023). The impact of AI chatbots on student engagement and reflective learning. *Interactive Learning Environments*. Advance online publication. <https://doi.org/10.1080/10494820.2023.2199987>
- Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning*, 2(1), 3–10. https://www.itdl.org/Journal/Jan_05/article01.htm
- Van Dijk, J. (2020). *The digital divide* (2nd ed.). Polity Press.
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.
- Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage Publications.

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Transforming Education Through Responsible Innovation and Inclusion in The Digital Era

Proceedings of the E-Learning International Conference, Kumasi, Ghana, 24-25 July, 2025

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