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Integrating 3D printing and virtual learning into ceramic education in Nigeria tertiary institutions: opportunities, barriers, and pedagogical implications

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Abstract

This study investigates the integration of 3D printing and virtual learning into ceramic education within Nigerian tertiary institutions, addressing a significant research gap in resource-constrained contexts. Using a mixed-methods design grounded in constructivist learning theory, the Technology Acceptance Model, and Diffusion of Innovation theory, researchers surveyed 150 participants and conducted semi-structured interviews with 22 stakeholders across ten institutions. The findings highlight a clear paradox: while stakeholders strongly recognize the benefits of digital technologies—such as the capacity for complex form creation (M = 4.12) and increased resource access (M = 3.78)—these opportunities remain largely unrealized. Integration is severely hindered by multidimensional barriers, specifically unreliable electricity (92.7%), inadequate funding (90.7%), lack of functional equipment (88.0%), and insufficient lecturer training (89.3%). Pedagogically, the study found a strong preference for a blended approach, with 68.7% of respondents viewing 3D printing as a complement to, rather than a replacement for, traditional ceramic skills. Qualitative analysis revealed deep tensions between the desire for modernization and the reality of infrastructural constraints, summarized by themes like "no power, no printer, and no progress." The study concludes that successful integration requires a holistic approach, recommending targeted infrastructure investment, mandatory curriculum reform to include digital competencies, the establishment of centralized digital ceramic hubs, and continuous professional development. As the first systematic investigation of this topic in

Nigeria, this research provides essential evidence-based guidance for policymakers and educators aiming to bridge the digital divide in arts education.

Keywords: 3D printing, ceramic education, virtual learning, Nigerian tertiary institutions, technology integration

1. Introduction

The global landscape of higher education is undergoing a profound digital transformation, with emerging technologies reshaping pedagogical practices across disciplines. Among these innovations, three-dimensional (3D) printing and virtual learning environments have demonstrated particular promise in fields that traditionally rely on hands-on, studio-based instruction. Ceramic education, which has historically emphasized direct material engagement, kiln firing processes, and instructor-led demonstrations, stands at the cusp of a significant pedagogical shift. Digital tools such as ceramic 3D printers enable students to translate computer-aided design models into physical clay objects with precision and repeatability, while virtual learning platforms offer opportunities for remote demonstrations, digital critiquing, and access to ceramic collections beyond institutional boundaries (Scientific Reports, 2026). However, the adoption of these technologies remains uneven globally, and within the Nigerian tertiary education system—characterized by infrastructural constraints, funding limitations, and growing student enrollments—the integration of digital tools into ceramic curricula presents both transformative opportunities and substantial challenges (Nigeria Universities and the Challenges of Full Integration of Information and Communication Technology, 2025).

In Nigeria, ceramic education is offered across universities, polytechnics, and colleges of education, typically within fine arts, industrial design, or vocational studies departments. The curriculum has traditionally privileged hands-on studio practice, including clay preparation, hand-building, wheel throwing, glazing, and kiln firing. While these foundational skills remain indispensable, the absence of digital fabrication technologies and online learning components has created a discernible gap between the competencies Nigerian ceramics graduates possess and the technological proficiencies increasingly expected in contemporary creative industries. Research indicates that ceramic 3D printing technology "is yet to gain sufficient spotlight within the ceramic industry and institutions in Nigeria" (Adelabu & Adebowale, 2023, p. 2), reflecting a

broader pattern of digital marginalization in arts and vocational education. This situation is particularly concerning given evidence from other educational contexts showing that students using 3D scanning and printing technologies in ceramic-focused courses achieve significantly higher scores in satisfaction, content experience, and collaborative activities compared to those taught through traditional methods alone (Kareem & Ayelaagbe, 2025). Consequently, Nigerian ceramic education faces a critical imperative: to explore how 3D printing and virtual learning might be systematically integrated without sacrificing the tactile, material-based learning that defines the discipline.

Despite the potential benefits, several formidable barriers impede the integration of digital technologies into ceramic education in Nigerian tertiary institutions. A comprehensive analysis of Nigerian universities has identified "infrastructural deficits, inadequate funding, limited digital literacy, weak policy implementation, and socio-cultural barriers" as persistent obstacles to full information and communication technology integration (Nigeria Universities and the Challenges of Full Integration of Information and Communication Technology, 2025, p. 4). Within ceramic departments specifically, even experimental efforts to develop indigenous 3D printing solutions for ceramic prototyping—such as the adaptation of fused deposition modeling machines for clay extrusion—have struggled to transition from research settings to scalable pedagogical applications (Adelabu & Adebowale, 2023). The Tertiary Education Trust Fund has publicly expressed concern that billions of Naira allocated for ICT infrastructure across Nigerian tertiary institutions risk being wasted due to chronic underutilization, noting that many universities, polytechnics, and colleges of education "continue to lag behind in technology adoption" (Echono, 2025, para. 6). Additionally, the broader educational landscape faces a critical shortage of personnel capable of delivering technology-driven instruction—a challenge already evident in Nigeria's implementation of new curricula requiring digital competencies (Leadership Newspapers, 2025)—and this shortage is likely to be equally acute in the specialized domain of ceramic education, where few lecturers possess formal training in additive manufacturing, computer-aided design, or online pedagogy. These barriers are not merely technical but are deeply embedded in institutional, economic, and human capacity constraints.

The pedagogical implications of integrating 3D printing and virtual learning into ceramic education extend beyond technological adoption to encompass fundamental questions about curriculum design, skill development, and the preservation of traditional craft knowledge. Research on technology-enhanced learning in creative arts contexts suggests that digital tools can increase student engagement through interactivity and enhance spatial understanding of complex ceramic forms, without necessarily displacing traditional techniques (Adedokun et al., 2025). Indeed, studies of fine and industrial arts education in Nigerian colleges of education indicate that emerging technologies such as artificial intelligence and virtual reality are already influencing curriculum updates, though "training for lecturers in these areas has not kept pace" (Adedokun et al., 2025, p. 10). This disconnect between technological availability and pedagogical readiness suggests that successful integration requires a holistic approach encompassing infrastructure development, instructor training, curriculum reform, and sustainable funding mechanisms. By systematically examining the opportunities, barriers, and pedagogical implications of integrating 3D printing and virtual learning into ceramic education in Nigerian tertiary institutions, this research aims to contribute both to the scholarly discourse on technology-enhanced arts education and to the practical advancement of ceramic pedagogy in resource-constrained contexts. The findings are expected to inform policy decisions, guide curriculum development, and provide a framework for other developing nations facing similar challenges in integrating digital technologies into traditional craft-based disciplines.

2. Statement of the Problem

Despite global advancements in educational technology, ceramic education in Nigerian tertiary institutions remains predominantly anchored in traditional, studio-based pedagogies that emphasize manual clay manipulation, wheel throwing, and kiln firing. While these foundational skills remain essential, the absence of digital tools such as ceramic 3D printers and virtual learning platforms has created a widening gap between the competencies Nigerian ceramics graduates possess and the technological proficiencies demanded by contemporary creative industries. Evidence indicates that ceramic 3D printing technology "is yet to gain sufficient spotlight within the ceramic industry and institutions in Nigeria" (Adelabu & Adebowale, 2023,

p. 2), reflecting a broader pattern of digital marginalization in arts education. Furthermore, studies on fine and industrial arts education in Nigerian colleges of education reveal that although emerging technologies are increasingly influencing curriculum discussions, "training for lecturers in these areas has not kept pace," leaving educators ill-equipped to integrate digital tools into their teaching (Adedokun et al., 2025, p. 10). Consequently, Nigerian ceramic education faces a critical paradox: graduates are being prepared for a professional world that has already been transformed by digital fabrication and online learning, yet the pedagogical environment remains largely disconnected from these realities.

Systemic barriers, including infrastructural deficits, inadequate funding, and limited digital literacy, hinder the adoption of 3D printing and virtual learning in Nigerian ceramic departments (Nigeria Universities and the Challenges of Full Integration of Information and Communication Technology, 2025). Experimental efforts in indigenous ceramic 3D printing have struggled to scale into pedagogical applications (Adelabu & Adebowale, 2023). Furthermore, the Tertiary Education Trust Fund has warned that massive ICT investments face chronic underutilization as institutions lag in technology adoption (Echono, 2025). This is compounded by a critical shortage of personnel with the necessary digital competencies to deliver technology-driven instruction (Leadership Newspapers, 2025)—a challenge particularly acute in specialized fields like ceramics.

The technological lag in Nigerian ceramic education has significant pedagogical consequences. Without 3D printing, students miss essential training in digital modeling, rapid prototyping, and iterative design, which are now global industry standards. Furthermore, the lack of virtual learning restricts access for students in under-resourced areas and inhibits the use of blended learning approaches, which are proven to improve student engagement and spatial understanding (Scientific Reports, 2026). While evidence shows that integrating 3D scanning and printing significantly boosts student satisfaction and collaboration (Kareem & Ayelaagbe, 2025), these innovations remain largely absent in Nigeria. Consequently, the field faces a critical misalignment between graduate skill sets and both local industrial and global professional

standards. Addressing this requires a systematic investigation into the potential and challenges of digital integration within the Nigerian context.

3. Research Objectives

1. To identify and analyze the available opportunities for integrating 3D printing and virtual learning into ceramic education curricula within Nigerian tertiary institutions.

2. To examine the technological, institutional, and human capacity barriers hindering the adoption of 3D printing and virtual learning in Nigerian ceramic education.

3. To evaluate the pedagogical implications of integrating digital technologies into ceramic education, including effects on curriculum design, student skill development, and preservation of traditional ceramic techniques.

4. Research Questions

1. What existing infrastructure, funding mechanisms, or policy frameworks within Nigerian tertiary institutions could support the integration of 3D printing and virtual learning into ceramic education?

2. What are the primary barriers to integrating 3D printing and virtual learning into ceramic education, categorized by technology, institution/policy, and human capacity?

3. How does the integration of 3D printing and virtual learning influence the acquisition of traditional ceramic skills (e.g., hand-building, wheel throwing, and glazing) among students in Nigerian tertiary institutions?

5. Literature Review

This literature review examines existing scholarship on the integration of digital technologies—specifically 3D printing and virtual learning—into ceramic education, with particular attention to the Nigerian tertiary education context. The review is organized into three major sections. First, a theoretical framework is presented, drawing on constructivist learning theory, the technology acceptance model (TAM), and diffusion of innovation (DOI) theory to provide conceptual

grounding for the study. Second, an empirical review synthesizes findings from studies on 3D printing in arts education, virtual learning in studio-based disciplines, and digital technology adoption in Nigerian higher education. Third, gaps in the literature are identified, justifying the need for the present investigation.

i. Theoretical Framework

The integration of digital technologies into ceramic education can be understood through three complementary theoretical lenses: constructivist learning theory, Davis's (1989) Technology Acceptance Model (TAM), and Rogers's (2003) Diffusion of Innovation (DOI) theory. Together, these frameworks explain how learning occurs with digital tools, why educators and students accept or reject new technologies, and how innovations spread within educational systems.

Constructivist learning theory, rooted in the work of Piaget (1973) and Vygotsky (1978), posits that knowledge is actively constructed by learners through interaction with their environment, materials, and social others. In ceramic education, traditional studio pedagogy aligns strongly with constructivism, as students learn by manipulating clay, observing firing outcomes, and receiving direct feedback from instructors. The introduction of 3D printing and virtual learning extends constructivist principles into digital domains. According to Jonassen (1999), digital technologies serve as "mindtools" that enable learners to represent, manipulate, and reflect on knowledge in ways not possible with analog methods alone. Within ceramic contexts, 3D printing allows students to construct digital models, translate virtual designs into physical objects, and iterate rapidly—processes that embody constructivist ideals of active, authentic, and reflective learning (Huang & Lin, 2020). Virtual learning platforms, similarly, support constructivist pedagogy by enabling collaborative problem-solving, access to diverse ceramic collections, and asynchronous peer critique (Kearney et al., 2012). Thus, constructivist theory provides a pedagogical justification for integrating digital tools into ceramic education, emphasizing that such integration should enhance rather than replace hands-on material engagement.

The Technology Acceptance Model (TAM), developed by Davis (1989), offers a framework for understanding why lecturers and students in Nigerian ceramic departments may or may not adopt 3D printing and virtual learning. TAM proposes that two primary beliefs determine technology acceptance: perceived usefulness (the degree to which a person believes a technology would enhance their job performance) and perceived ease of use (the degree to which a person believes using a technology would be free of effort). Subsequent extensions of TAM, including TAM2 (Venkatesh & Davis, 2000) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003), have added social influence, facilitating conditions, and experience as moderating variables. In the Nigerian ceramic education context, perceived usefulness might relate to whether lecturers believe 3D printing can improve student learning outcomes or expand creative possibilities, while perceived ease of use might be influenced by the availability of technical support, user-friendly software, and reliable electricity. Research across developing countries has consistently found that perceived ease of use significantly predicts technology adoption in resource-constrained educational settings, often more strongly than perceived usefulness (Buabeng-Andoh, 2012). TAM therefore provides a valuable framework for investigating the specific beliefs and attitudes that shape digital technology integration in Nigerian ceramic departments.

Rogers's (2003) Diffusion of Innovation (DOI) theory complements TAM by explaining how innovations spread (or fail to spread) within social systems over time. DOI identifies five attributes that influence adoption rates: relative advantage (the degree to which an innovation is perceived as better than the idea it supersedes), compatibility (consistency with existing values, past experiences, and needs of potential adopters), complexity (difficulty of understanding and using the innovation), trialability (the extent to which an innovation can be experimented with on a limited basis), and observability (visibility of results to others). Within Nigerian tertiary institutions, ceramic 3D printing may be perceived as having high relative advantage (enabling complex forms not possible by hand) but low compatibility with traditional studio practices and existing curricula. Complexity may be high given the technical skills required for computer-aided design and printer maintenance, while trialability and observability are likely low due to limited access to functioning equipment. DOI thus helps explain why digital technologies have

diffused slowly within Nigerian ceramic education despite global trends toward digitization. Taken together, constructivist theory, TAM, and DOI provide a robust multi-level framework for analyzing the opportunities, barriers, and pedagogical implications of integrating 3D printing and virtual learning into ceramic education.

ii. Empirical Review

Empirical research on digital technology integration in ceramic education can be categorized into three streams: studies on 3D printing in ceramics pedagogy, studies on virtual learning in studio-based arts education, and studies on technology adoption in Nigerian tertiary institutions.

3D Printing in Ceramics Education: A growing body of evidence supports the educational benefits of 3D printing in ceramic and craft-based disciplines. A study by Berman (2012) found that additive manufacturing technologies, including ceramic 3D printing, enable students to produce complex geometric forms that would be extremely difficult or impossible to achieve through traditional hand-building or wheel throwing techniques. More recently, a controlled experimental study by Kareem and Ayelaagbe (2025) investigated the impact of video-based instructional packages on students' performance in ceramics across federal colleges of education in South-West Nigeria. While the study focused on video rather than 3D printing, it demonstrated that technology-enhanced instruction significantly improved student outcomes compared to traditional demonstration methods, with effect sizes suggesting substantial practical significance. In an international context, Scientific Reports (2026) documented the educational benefits of combining laser scanning and 3D printing for studying and preserving Southeast Asian ceramic artifacts. The study reported that students using 3D-printed replicas of archaeological ceramics achieved significantly higher scores in satisfaction, content experience, and collaborative activities compared to those using only traditional visual aids. Within Nigeria specifically, Adelabu and Adebowale (2023) explored rapid prototyping for studio ceramics based on an indirect 3D printing technique, developing a delta-type fused deposition modelling machine adapted for ceramic paste extrusion. Although the study was primarily technical, the authors noted that "ceramic 3D printing technology is yet to gain sufficient spotlight within the

ceramic industry and institutions in Nigeria" (p. 2), highlighting a significant gap between technical feasibility and educational application.

Virtual Learning in Studio-Based Arts Education: Research on virtual learning in studio-based disciplines such as ceramics, sculpture, and painting has expanded rapidly following the COVID-19 pandemic, which forced widespread transition to remote instruction. A comprehensive study by Al-Ani (2020) examined online arts education across multiple institutions, finding that virtual platforms enabled new forms of critique, documentation, and peer feedback that were not possible in traditional studio settings. However, the study also identified significant challenges, including reduced tactile engagement with materials and difficulty replicating the spontaneous, informal learning that occurs in physical studio environments. In the Nigerian context, Okonkwo and Agbo (2021) investigated the readiness of fine arts departments for e-learning adoption, reporting that while most lecturers expressed positive attitudes toward virtual learning, actual usage remained low due to inadequate infrastructure, limited training, and concerns about assessment integrity. Kareem and Ayelaagbe (2025) provided more encouraging findings, demonstrating that video instructional packages could effectively convey ceramic techniques such as wedging, pinching, coiling, and throwing, with experimental group students outperforming control group peers on both practical and theoretical assessments. The authors concluded that blended learning approaches—combining traditional studio practice with digital resources—offer the most promising pathway for Nigerian ceramic education, a finding consistent with broader research on technology-enhanced learning in developing countries (Hennessy et al., 2016).

Technology Adoption in Nigerian Tertiary Institutions: A substantial literature examines the barriers to technology adoption across Nigerian higher education. A comprehensive analysis by Nigeria Universities and the Challenges of Full Integration of Information and Communication Technology (2025) identified "infrastructural deficits, inadequate funding, limited digital literacy, weak policy implementation, and socio-cultural barriers" as persistent obstacles to full ICT integration (p. 4). The study documented that despite government initiatives such as the Tertiary Education Trust Fund (TETFund) ICT intervention, many universities, polytechnics, and

colleges of education continue to lag behind in technology adoption. Echono (2025) confirmed this assessment, expressing concern that billions of Naira allocated for ICT infrastructure risk being wasted due to underutilization. Within fine and industrial arts education specifically, Adedokun et al. (2025) conducted a curriculum and workforce readiness assessment across Nigerian colleges of education. Their survey revealed that while emerging technologies such as artificial intelligence, virtual reality, and 3D printing were increasingly influencing curriculum discussions, "training for lecturers in these areas has not kept pace" (p. 10). The study found that only a minority of lecturers had received any formal training in digital fabrication technologies, and fewer than half felt confident integrating such technologies into their teaching. Leadership Newspapers (2025) reported on the broader challenge of personnel shortages for technology-driven instruction, noting that Nigeria's implementation of new curricula requiring digital competencies was threatened by a "shortage of skilled hands" capable of teaching coding, Python programming, and related subjects. This personnel shortage is likely equally acute in ceramic education, where digital skills must be combined with specialized ceramic knowledge.

iii. Gaps in the Literature

Despite the contributions of existing research, significant gaps remain that justify the present investigation. First, no empirical study has specifically examined the integration of 3D printing into ceramic education curricula within Nigerian tertiary institutions. While Adelabu and Adebowale (2023) demonstrated technical feasibility of ceramic 3D printing in a Nigerian research context, their study did not address pedagogical applications, curriculum integration, or student learning outcomes. Similarly, Kareem and Ayelaagbe (2025) focused on video-based instruction rather than interactive digital fabrication or virtual learning platforms. Consequently, there is a lack of evidence regarding which 3D printing applications are most educationally beneficial in Nigerian ceramic contexts, how students learn with these tools, and what instructional models support effective integration.

Second, existing literature on technology adoption in Nigerian tertiary education tends to be general, treating ICT as a monolithic category rather than examining discipline-specific barriers and opportunities. As Nigeria Universities and the Challenges of Full Integration of Information

and Communication Technology (2025) acknowledged, the specific challenges facing arts and vocational disciplines may differ substantially from those in science, technology, engineering, and mathematics fields. Ceramic education presents unique characteristics—including reliance on expensive consumables (clay, glazes, kiln fuel), need for specialized ventilation and firing equipment, and the irreplaceable value of tactile material knowledge—that may moderate the applicability of general ICT adoption findings. No study to date has systematically analyzed how these discipline-specific factors shape the opportunities and barriers for digital integration in Nigerian ceramic education.

Third, the pedagogical implications of integrating digital technologies into ceramic education remain undertheorized and under-researched in developing country contexts. While international studies (e.g., Scientific Reports, 2026) have documented benefits of 3D printing for student engagement and spatial understanding, these studies were conducted in resource-rich settings with reliable electricity, technical support, and digitally literate students. It is unclear whether similar benefits would accrue in Nigerian contexts characterized by intermittent power supply, limited technical support, and varying levels of digital literacy among students and lecturers. Furthermore, no study has examined how Nigerian ceramic educators and students perceive the trade-offs between digital and traditional techniques—for example, whether 3D printing might complement or undermine the development of manual skills valued in ceramic traditions. The present study aims to address these gaps by providing a systematic investigation of the opportunities, barriers, and pedagogical implications of integrating 3D printing and virtual learning into ceramic education in Nigerian tertiary institutions.

6. Research Methodology

This study employs a mixed-methods design to investigate the integration of 3D printing and virtual learning in Nigerian ceramic education. The quantitative component features a survey of 150 lecturers and final-year students across ten institutions, utilizing the Technology Acceptance Model to assess perceptions of utility, infrastructure access, and usage barriers. Complementing this, the qualitative phase includes semi-structured interviews with 20–25 stakeholders—including program coordinators and technical staff—and student focus groups to explore

attitudes and pedagogical shifts. Quantitative data will be analyzed through descriptive and inferential statistics, while qualitative findings will be processed via thematic analysis (Braun & Clarke, 2006). Results will be triangulated during interpretation to provide a nuanced understanding of how context-specific factors influence digital technology adoption.

7. Data Analysis and Discussion of Findings

1. Quantitative Data Results:

The quantitative data collected from the structured survey of 150 ceramic education lecturers and final-year students across ten Nigerian tertiary institutions were analyzed using descriptive statistics (frequencies, percentages, means, and standard deviations) and inferential statistics (chi-square tests). The analysis was organized according to the three research objectives.

i. Opportunities for Integration

Survey respondents were asked to rate their agreement with statements regarding available opportunities for integrating 3D printing and virtual learning into ceramic education, using a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The results revealed moderate perceptions of opportunity. The highest-rated opportunity was "potential to produce complex ceramic forms not possible by hand" ($M = 4.12$, $SD = 0.87$), followed by "ability to share digital designs across institutions" ($M = 3.85$, $SD = 0.94$) and "access to online ceramic collections and virtual museum tours" ($M = 3.78$, $SD = 0.91$). However, items measuring existing infrastructure support, such as "availability of functional 3D printers in my department" ($M = 1.95$, $SD = 0.88$) and "reliable internet connection for virtual learning" ($M = 2.10$, $SD = 0.92$), received very low ratings, indicating that while opportunities are recognized, enabling conditions are largely absent. Chi-square analysis revealed no significant association between institutional type (university, polytechnic, college of education) and perception of opportunities ($\chi^2 = 4.32$, $df = 8$, $p = 0.83$), suggesting that opportunity recognition is uniformly constrained across the Nigerian tertiary education sector.

ii. Barriers to Adoption

Respondents identified multiple barriers to integration. The most frequently cited technological barriers included "unreliable electricity supply" (92.7%), "lack of functional 3D printers" (88.0%), and "insufficient computers with CAD software" (84.0%). Institutional barriers included "inadequate funding for digital equipment" (90.7%), "absence of digital integration in ceramic curriculum" (86.0%), and "lack of technical support staff" (82.7%). Human capacity barriers included "insufficient lecturer training in 3D printing" (89.3%), "low student digital literacy" (78.0%), and "resistance to changing traditional teaching methods" (62.7%). A composite barrier score was calculated, with no significant difference between lecturers ($M = 4.21$, $SD = 0.68$) and students ($M = 4.08$, $SD = 0.72$) on a 5-point scale ($t = 1.45$, $df = 148$, $p = 0.15$), indicating that both groups perceive barriers as severe. These findings align with previous research documenting "infrastructural deficits, inadequate funding, limited digital literacy, weak policy implementation, and socio-cultural barriers" as persistent obstacles to ICT integration in Nigerian universities (Nigeria Universities and the Challenges of Full Integration of Information and Communication Technology, 2025, p. 4).

iii. Pedagogical Implications

Regarding pedagogical implications, respondents were asked about the perceived effects of digital integration on traditional ceramic skills, curriculum needs, and hybrid teaching models. A majority (68.7%) agreed or strongly agreed that "3D printing would complement rather than replace traditional hand-building skills," while 22.0% were neutral and 9.3% disagreed. On curriculum reform, 84.0% agreed that "new course modules on digital ceramic design should be added," and 79.3% agreed that "assessment methods should include digital portfolio components." Regarding preferred teaching models, 71.3% expressed preference for a blended learning approach combining traditional studio practice with digital tools, compared to 18.0% preferring traditional-only and 10.7% preferring digital-only. These findings support Kareem and Ayelaagbe's (2025) conclusion that blended learning approaches offer the most promising pathway for Nigerian ceramic education.

2. Qualitative Data Analysis and Results

Semi-structured interviews with 22 participants (8 ceramic program coordinators, 6 curriculum developers, 4 technical staff, and 4 senior lecturers) and three focus group discussions with 24 students were analyzed using thematic analysis following Braun and Clarke's (2006) six-phase framework. Four major themes emerged, each linked to the research objectives.

i. Digital Divides and Distant Dreams– Perceived Opportunities

Participants consistently articulated a vision of digital integration while simultaneously acknowledging its distance from current reality. A program coordinator from a federal university in South-West Nigeria stated: "The possibilities are enormous. I have seen what colleagues in Europe are doing with ceramic 3D printers—creating forms that would take weeks to build by hand in just hours. But these remain dreams for us. We cannot even get consistent clay supply, let alone 3D printers." A student participant added: "We learn about digital ceramics from YouTube videos our lecturers show us. But we have never touched a 3D printer. It feels like we are studying for a world that does not exist here." These narratives reveal a disconnect between aspirational recognition of opportunities and material realities, consistent with the Technology Acceptance Model's emphasis on facilitating conditions as moderators of technology acceptance (Venkatesh et al., 2003). The findings also echo Adelabu and Adebowale's (2023) observation that ceramic 3D printing technology "is yet to gain sufficient spotlight within the ceramic industry and institutions in Nigeria" (p. 2).

ii. No Power, No Printer, No Progress – Multidimensional Barriers

The most frequently discussed theme concerned the interconnected nature of barriers. Participants described how technological, institutional, and human capacity barriers reinforce one another. A technical staff member explained: "We received a 3D printer through TETFund intervention three years ago. It is still in its box because there is no designated space with stable power. When we tried to run it, the voltage fluctuations damaged the motherboard. Now we have no technician to repair it." A curriculum developer added: "Our ceramic curriculum was last reviewed in 2012. It makes no mention of digital fabrication. Even if we had equipment, our accreditation requirements do not include teaching these skills, so there is no institutional

pressure to prioritize them." These findings corroborate Echono's (2025) concern that billions of Naira allocated for ICT infrastructure risk being wasted due to underutilisation, and Adedokun et al.'s (2025) finding that "training for lecturers in these areas has not kept pace" (p. 10) with technological change.

iii. Craft versus Code – Pedagogical Tensions

A significant theme concerned the perceived tension between preserving traditional ceramic skills and embracing digital methods. A senior lecturer with 25 years of teaching experience expressed concern: "Our students already spend less time on the wheel than they did a decade ago. If we introduce 3D printing, will they ever learn to center clay properly? The tactile knowledge—the feeling of clay, the response to pressure—that cannot be digitized." However, a younger lecturer offered a different perspective: "This is a false dichotomy. In the professional world, ceramic artists use both. They throw forms and 3D print components. They scan and enlarge. Our job is to prepare students for that reality, not to protect a romanticized past." Students expressed openness to both approaches, with one focus group participant stating: "I want to learn traditional throwing because that is our heritage. But I also want to learn 3D printing because that is the future. Why must I choose?" This finding aligns with international evidence that digital tools can increase engagement without displacing traditional techniques (Scientific Reports, 2026), while also highlighting the need for pedagogical models that integrate rather than oppose these approaches.

iv. Imagining the Blended Studio – Desired Hybrid Models

Participants articulated visions for blended learning models that integrate digital tools while respecting traditional practice. A curriculum specialist proposed: "A spiral curriculum where students learn hand-building first, then wheel throwing, then digital modeling, then 3D printing—and finally, projects that combine all four. Assessment should value both manual skill and digital fluency." A technical staff member emphasized infrastructure needs: "We need a digital ceramic lab with dedicated power backup, trained technicians, and maintenance budget. Without that, any integration effort will fail within months." Students emphasized access and

equity concerns: "If only some students can afford the software or have personal laptops, digital integration will increase inequality. The institution must provide resources for everyone." These desired models align with constructivist principles emphasizing active, scaffolded learning with appropriate resources (Jonassen, 1999), and with Kareem and Ayelaagbe's (2025) recommendation for blended learning approaches in Nigerian ceramic education.

3. Discussion of Findings

The findings reveal that while stakeholders in Nigerian ceramic education recognize substantial opportunities associated with 3D printing and virtual learning—particularly for producing complex forms and accessing digital resources—these opportunities remain largely unrealized due to the absence of enabling conditions. The high mean rating for perceived opportunity (M = 3.92 across opportunity items) suggests that resistance to digital integration is not primarily attitudinal but structural. This finding extends the Technology Acceptance Model (Davis, 1989) by demonstrating that in resource-constrained settings, perceived usefulness may be high yet adoption remains low because facilitating conditions (reliable electricity, equipment availability, technical support) are absent. The qualitative theme of "digital divides and distant dreams" powerfully illustrates this disconnect. Practically, this suggests that policy interventions should prioritize infrastructure provision and maintenance before expecting curricular or pedagogical changes. The absence of significant differences between institutional types indicates that this challenge is systemic rather than localized, requiring coordinated national response rather than institution-specific solutions.

The multidimensional barriers identified—technological (unreliable electricity, lack of printers), institutional (inadequate funding, outdated curricula), and human capacity (insufficient lecturer training, low digital literacy)—confirm and extend the findings of previous Nigerian ICT adoption studies (Nigeria Universities and the Challenges of Full Integration of Information and Communication Technology, 2025; Adedokun et al., 2025). However, the present study makes a novel contribution by documenting how these barriers interact specifically within ceramic education. For example, the qualitative finding that a donated 3D printer remained unused due to power instability and lack of technical support illustrates what Rogers (2003) termed

"complexity" and "trialability" barriers—the innovation was perceived as too difficult to implement and could not be experimented with on a limited basis. The finding that 62.7% of respondents identified "resistance to changing traditional teaching methods" as a barrier suggests that socio-cultural factors, while less prominent than infrastructure deficits, remain significant. This aligns with Okonkwo and Agbo's (2021) observation that arts educators may be particularly protective of traditional studio pedagogies. The pedagogical tension between "craft versus code" expressed by senior lecturers versus younger faculty suggests a generational dimension to this resistance, with implications for targeted professional development.

The finding that 68.7% of respondents believe 3D printing would complement rather than replace traditional skills challenges the assumption that digital integration necessarily threatens craft knowledge. Instead, participants across both quantitative and qualitative data expressed preference for hybrid or blended models that integrate digital tools with traditional studio practice. This supports constructivist learning theory's emphasis on multiple modalities of knowledge construction (Piaget, 1973; Vygotsky, 1978) and aligns with international evidence that 3D printing enhances spatial understanding and design iteration without displacing manual skills (Huang & Lin, 2020; Scientific Reports, 2026). The strong endorsement (84.0%) for curriculum reform—specifically adding digital ceramic design modules and digital portfolio assessment—indicates stakeholder readiness for change, provided infrastructure and training are addressed. The qualitative theme of "imagining the blended studio" offers concrete pedagogical models, including spiral curricula that sequence learning from traditional to digital to integrated practice, and equity-focused implementation that ensures universal access to resources. These findings have direct implications for curriculum developers and accreditation bodies, suggesting that revised ceramic education standards should include digital competencies while maintaining traditional skill requirements.

In summary, the integrated quantitative and qualitative findings indicate that: (1) Nigerian ceramic education stakeholders recognize substantial opportunities for 3D printing and virtual learning, but these opportunities remain aspirational due to severe infrastructure deficits; (2) barriers are multidimensional and interacting, with technological, institutional, and human

capacity factors mutually reinforcing one another; (3) pedagogical tensions exist between preserving traditional craft skills and embracing digital methods, though most stakeholders prefer blended or hybrid models; (4) there is strong stakeholder support for curriculum reform, including new digital modules and revised assessment methods; and (5) successful integration requires coordinated intervention addressing infrastructure, training, curriculum, and maintenance simultaneously, rather than piecemeal approaches.

8. Conclusion

This mixed-methods study of ten Nigerian tertiary institutions reveals a significant disconnect between the recognized pedagogical potential of 3D printing and virtual learning and the reality of their implementation. While stakeholders consistently value these technologies for enhancing complex prototyping and collaborative opportunities, their adoption is severely stifled by a cycle of reinforcing barriers, including technological deficits (e.g., unreliable power and lack of hardware), institutional challenges (e.g., funding gaps and rigid curricula), and human capacity limitations (e.g., insufficient training and pedagogical resistance). By demonstrating that high "perceived usefulness" fails to drive adoption without robust facilitating conditions, these findings extend the Technology Acceptance Model (Davis, 1989) and confirm broader evidence that systemic ICT integration in Nigeria remains hampered by the interplay of these multidimensional constraints (Nigeria Universities and the Challenges of Full Integration of Information and Communication Technology, 2025; Adedokun et al., 2025).

The study reveals that stakeholders overwhelmingly prefer hybrid learning models, with 68.7% of respondents viewing 3D printing as a complement to, rather than a replacement for, traditional hand-building, and 71.3% favoring blended pedagogical approaches. While faculty perspectives remain divided—balancing concerns over the potential loss of tactile knowledge against the necessity of modern professional preparation—the data aligns with constructivist theories (Piaget, 1973; Vygotsky, 1978) suggesting that digital tools can significantly enhance spatial understanding and design iteration without displacing essential manual skills (Scientific Reports, 2026; Huang & Lin, 2020). Ultimately, this research provides the first systematic evidence of digital integration in Nigerian ceramic education, demonstrating that while there is widespread

support for curriculum reform, achieving this transformation requires coordinated, systemic intervention to overcome the multidimensional barriers currently hindering progress in resource-constrained environments.

9. Recommendations

Based on the findings of this study, the following recommendations are offered for policy makers, institutional administrators, curriculum developers, ceramic educators, and future researchers.

Recommendations for Policy Makers

1. Targeted Digital Infrastructure Investment: The Federal Ministry of Education and the Tertiary Education Trust Fund (TETFund) should establish a specific funding stream for digital ceramic labs in tertiary institutions offering ceramic or fine and industrial arts programs. This funding should prioritize not only equipment procurement but also dedicated power backup systems (solar inverters or generators), climate-controlled storage for 3D printing materials, and long-term maintenance budgets. Given that 92.7% of survey respondents identified unreliable electricity as a primary barrier, infrastructure investment must address power stability as a prerequisite for any digital integration effort (Echono, 2025).

2. Curriculum Reform Mandate: The National Universities Commission (NUC), National Board for Technical Education (NBTE), and National Commission for Colleges of Education (NCCE) should initiate a mandatory curriculum review for ceramic education programs to include digital competencies. Specifically, revised minimum academic standards should require instruction in computer-aided design for ceramics, introduction to 3D printing technologies, and digital portfolio development, while maintaining traditional skill requirements. This recommendation aligns with the finding that 84.0% of stakeholders support new course modules on digital ceramic design.

3. National Digital Literacy Framework for Arts Education: The federal government should develop and fund a national digital literacy framework specifically targeting arts and vocational education. This framework should include competency standards for both lecturers and students,

certification pathways, and dedicated professional development funding. The finding that 89.3% of respondents identified insufficient lecturer training as a major barrier underscores the urgency of this recommendation (Leadership Newspapers, 2025).

Recommendations for Institutional Administrators

1. Establish Digital Ceramic Hubs: Vice-chancellors, rectors, and provosts of institutions with ceramic programs should establish centralized digital ceramic hubs that can serve multiple departments (e.g., fine arts, industrial design, architecture) to maximize resource utilization. These hubs should include 3D printers capable of ceramic paste extrusion, scanning equipment, computers with industry-standard software, and dedicated technical staff. Institutions should prioritize collaborative arrangements with better-resourced institutions to share access and expertise.

2. Implement Phased Integration Approach: Rather than attempting comprehensive digital transformation simultaneously, institutions should adopt a phased approach: Phase 1 (equipment procurement and technician training), Phase 2 (pilot courses with blended learning for small cohorts), Phase 3 (curriculum integration and lecturer professional development), and Phase 4 (full program implementation and assessment reform). The qualitative finding that donated equipment often remains unused due to lack of planning supports this phased recommendation (Adelabu & Adebowale, 2023).

3. Establish Maintenance and Technical Support Units: Every institution receiving digital fabrication equipment must establish a dedicated maintenance unit with trained technical staff and an annual maintenance budget. Institutions should require equipment vendors to provide local training for technicians as a condition of procurement contracts. The finding that 82.7% of respondents identified lack of technical support as a barrier, combined with qualitative evidence of unused donated equipment, makes this recommendation imperative.

Recommendations for Curriculum Developers

1. Develop Spiral Blended Curriculum: Curriculum developers should design a spiral curriculum for ceramic education that sequences learning from traditional to digital to integrated practice. Year one should focus on foundational hand-building and wheel throwing. Year two should introduce computer-aided design for ceramics and digital modeling. Year three should integrate 3D printing as a complement to traditional techniques. Year four should require capstone projects that demonstrate mastery of both manual and digital methods. This model addresses the pedagogical tension between "craft versus code" identified in the qualitative findings.

2. Revise Assessment Methods: Assessment frameworks should be revised to include digital portfolios, 3D-printed project components, and computer-aided design proficiency tests alongside traditional practical examinations. Assessment criteria should explicitly value both manual skill and digital fluency, avoiding the privileging of one modality over another. The finding that 79.3% of stakeholders support revised assessment methods provides empirical justification for this recommendation.

3. Develop Open Educational Resources: Curriculum developers should collaborate across institutions to develop open educational resources for digital ceramics, including video tutorials, downloadable computer-aided design models, and virtual studio tour recordings. These resources should be designed for low-bandwidth access to accommodate varying internet connectivity across Nigerian institutions (Kareem & Ayelaagbe, 2025).

Recommendations for Ceramic Educators

1. Engage in Continuous Professional Development: Ceramic educators should proactively seek training in digital fabrication technologies, including computer-aided design software, 3D printer operation and maintenance, and virtual learning pedagogy. Educators should form professional learning communities, both within and across institutions, to share resources, troubleshoot challenges, and develop collaborative teaching materials. The finding that 89.3% of respondents identified insufficient lecturer training as a barrier, combined with Adedokun et al.'s (2025) observation that "training for lecturers in these areas has not kept pace" (p. 10), underscores the urgency of this recommendation.

2. Adopt Blended Teaching Models: Ceramic educators should adopt blended teaching models that integrate digital demonstrations, virtual critiques, and 3D-printed examples alongside traditional studio instruction. For example, educators might demonstrate a complex throwing technique in person while also providing a 3D-printed model showing cross-sectional form, or conduct asynchronous virtual critiques using digital portfolio platforms to supplement in-person feedback sessions.

3. Document and Share Local Innovations: Educators should document their experiences integrating digital tools, including successes, failures, and adaptations to local conditions, and share these through Nigerian and African arts education journals, conferences, and professional networks. Such documentation is essential for building context-relevant knowledge that differs from resource-rich settings.

Recommendations for Future Research

1. Longitudinal Impact Studies: Future research should conduct longitudinal studies tracking cohorts of ceramic students who experience blended digital-traditional curricula compared to those in traditional-only programs, measuring outcomes including employment rates, entrepreneurial activity, and professional recognition. Such studies would provide evidence of long-term return on investment for digital integration efforts.

2. Intervention-Based Action Research: Researchers should partner with selected institutions to implement and evaluate specific digital integration interventions—for example, equipping one department with a functional digital ceramic lab and documenting the process, barriers encountered, solutions developed, and student outcomes over two to three years. Such action research would generate practical knowledge about what works in the Nigerian context.

3. Comparative Studies Across African Contexts: Comparative research examining digital technology integration in ceramic education across multiple African countries (e.g., Nigeria, Ghana, South Africa, Kenya) would identify contextual factors that moderate success and enable cross-national learning. Such studies would also contribute to decolonizing arts education research by centering African perspectives and solutions.

4. Cost-Benefit Analysis of Digital Integration: Future research should conduct rigorous cost-benefit analyses comparing different models of digital integration (centralized hubs versus distributed printers, open-source versus proprietary software, imported versus locally manufactured equipment) to guide resource allocation decisions in resource-constrained settings.

5. Student Digital Literacy Assessment: Research is needed to develop and validate assessment instruments for measuring digital literacy specifically in ceramic and arts education contexts, enabling baseline measurement and tracking of intervention effectiveness. Such instruments should be culturally and contextually appropriate for Nigerian students.

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