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Empirical Paper

Effects of an 80-10-10 Multilingual CTCA-Harlybot Model on Achievement and Critical Thinking in Mobile and Adaptive Systems

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Abstract

Purpose: This study compared three instructional approaches for teaching a Mobile and Adaptive Systems course: traditional lecture, Harlybot-supported Culturo-Techno-Contextual Approach (CTCA) in English, and Harlybot-supported CTCA using an 80-10-10 English–Nigerian Pidgin–Yoruba code-switching model. It examined their effects on students' achievement (retention) and critical-thinking skills.

Methodology: A pre-test–post-test quasi-experimental design involving 75 second-year undergraduates was adopted. Cognitive Task Analysis identified the OSI Model as the most difficult concept, informing the intervention. Quantitative data were analysed using MANCOVA with pre-test scores as covariates, while think-aloud protocols and focus groups provided qualitative evidence.

Results: No statistically significant differences were found across the three approaches ($p > .05$). However, the multilingual CTCA group consistently achieved the highest adjusted mean scores for achievement and critical thinking, with moderate-to-large effect sizes ($\eta^2 = .09–.14$). Qualitative findings showed that strategic, culturally grounded code-switching reduced extraneous cognitive load and enhanced meaningful learning.

Novelty and Contributions: The study extends Okebukola's Eco-Techno-Cultural Theory by identifying an optimal indigenous-language threshold (≤20%) for teaching complex computing concepts and demonstrating the effectiveness of integrating AI-supported instruction, CTCA, and multilingual pedagogy.

Practical and Social Implications: The findings suggest that limited, purposeful AI-supported code-switching can improve learning while preserving academic rigour, thereby providing a culturally responsive approach to STEM education in multilingual African universities.

Keywords: Culturo-Techno-Contextual Approach-2.0, chatbot, multilingual scaffolding, 80-10-10 model, Mobile and Adaptive Systems, OSI Model

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1 Introduction

The teaching of Mobile and Adaptive Systems at university level remains one of the most stubbornly difficult areas in computer science and information technology curricula worldwide. The course demands that learners master not only the visible components of mobile devices and applications, but also a host of invisible, abstract, and highly sequential processes of encapsulation and de-encapsulation in the OSI model, context-aware computing, dynamic user modelling, real-time feedback loops, and adaptive path-switching algorithms. These concepts sit at the dangerous intersection of high intrinsic cognitive load and almost complete absence of everyday experiential referents for the average African undergraduate (Oladejo et al., 2023). In Nigeria, the official medium of instruction is English, yet fewer than 20 % of homes speak English as a first language (Obiakor, 2024); the linguistic and cultural distance between the learner's lived reality and the technical discourse of the OSI layers becomes a formidable barrier. Students repeatedly describe encapsulation as "a spirit wearing seven different clothes" or "juju inside the phone", revealing a profound affective and conceptual alienation that traditional lecture methods have failed to bridge.

The Culturo-Techno-Contextual Approach (CTCA), developed by Distinguished Emeritus Professor Peter A. Okebukola, has emerged over the last two decades as one of Africa's most successful indigenous responses to this exact problem. CTCA insists that effective STEM learning in African contexts must deliberately weave together three inseparable strands: the cultural world of the learner, the technological tool being deployed, and the immediate socio-academic context. Numerous large-scale studies in biology, chemistry, and physics (Okebukola et al., 2020; Awaah et al., 2022) have demonstrated that when teachers strategically infuse familiar cultural analogies, proverbs, and limited code-switching into technology-rich lessons, achievement and attitude soar. Yet, until now, CTCA has never been systematically applied to the teaching of Mobile and Adaptive Systems, nor has it been operationalised through an artificial-intelligence chatbot capable of delivering precisely calibrated multilingual interactions in real time.

At the core of the interventions adopted for this study is Harlybot, an AI conversational agent purpose-built by the present researcher to embody the principles of CTCA. Unlike generic chatbots or international systems such as Woebot or Jill Watson (Chen et al., 2020), Harlybot was designed from the ground up to recognise and respond in Nigerian Pidgin and Yoruba at pedagogically critical moments while preserving academic English as the default register. The core innovation tested in this study is the 80-10-10 multilingual delivery model: 80 % of every explanation remains in formal academic English (to maintain university-level rigour and global readability). In comparison, 10 % is delivered in Nigerian Pidgin and 10 % in Yoruba, strategically timed to coincide with the exact cognitive bottlenecks previously identified through Cognitive Task Analysis (CTA) —chiefly the encapsulation/de-encapsulation processes and the routing of data bi-directionally via the 7 layers of the OSI model. This deliberate dosage represents the first empirical attempt to quantify how much "cultural air" is needed to breathe life into an otherwise suffocating abstract concept without collapsing the academic atmosphere entirely.

Preliminary Cognitive Task Analysis conducted with 75 undergraduates and 12 expert-novice pairs in south-western Nigeria revealed a near-unanimous verdict: the OSI model and its invisible layer interactions constitute the single most difficult topic in the entire Mobile and Adaptive Systems curriculum. Students could memorise the seven layers and recite them flawlessly, yet when asked to explain how a WhatsApp message "wears coat upon coat" as it descends the stack and "removes coat" on the way up, the vast majority resorted to mystical metaphors or simply fell silent. This finding is not unique to Nigeria; international studies report similar struggles (Wu et al., 2024), but the intensity of affective rejection ("I hate this topic", "it makes me feel stupid") appears markedly higher in multilingual African settings where the explanatory language itself feels foreign. It is precisely this triple burden such as high intrinsic load, linguistic alienation, and cultural disconnection that this present study sets out to confront.

Despite the acknowledged difficulty of the OSI model and related concepts, university lecturers in Nigeria continue to rely almost exclusively on English-only lecture methods and PowerPoint slides that were originally designed for monolingual Western audiences. The result is predictable: low conceptual mastery, poor retention of abstract processes, diminished critical-thinking skills when solving adaptive-system problems, and most damaging of all, a deep-seated negative attitude toward a field that students must master to participate in Africa's digital future. While the broader CTCA framework has transformed science education outcomes, no study has yet tested whether a chatbot-delivered, precisely calibrated 80-10-10 multilingual version of CTCA can outperform both traditional lecture and monolingual chatbot-supported instruction in the specific context of Mobile and Adaptive Systems. This study fills

that gap by asking whether deliberate, theory-driven code-switching at the 20 % threshold can finally make the invisible layers of the OSI model visible, meaningful, and even likeable to Nigerian undergraduates.

Research Questions

i. To what extent does the Harlybot-supported Culturo-Techno-Contextual Approach (CTCA), delivered in an 80-10-10 multilingual mode, differ from traditional lecture and monolingual chatbot delivery in promoting achievement (retention) in Mobile and Adaptive Systems?

ii. To what extent does the 80-10-10 multilingual CTCA-Harlybot model differ from the other two approaches in developing critical-thinking skills in Mobile and Adaptive Systems?

iii. What qualitative mechanisms explain any observed differences in achievement and critical-thinking outcomes across the three delivery modes?

Hypotheses

Ho_1: There is no significant difference in post-test achievement (retention) scores in Mobile and Adaptive Systems among students taught using traditional lecture, monolingual Harlybot-CTCA, and 80-10-10 multilingual Harlybot-CTCA after controlling for pre-test scores.

Ho_2: There is no significant difference in post-test critical-thinking scores among the three groups after controlling for pre-test scores.

Theoretical and Philosophical Underpinnings of the Study

The study is anchored primarily on the Culturo-Techno-Contextual Approach (CTCA), an indigenous African pedagogical framework developed by Distinguished Emeritus Professor Peter A. Okebukola between 1999 and 2020 (Okebukola, 2019). CTCA is explicitly decolonial in its philosophy: it rejects the universalist assumption that effective teaching can be culture-free or culture-neutral. Instead, it insists that in African learning ecologies, culture is not an optional add-on but the very soil in which both technology and context must be rooted for knowledge to germinate. Okebukola (2020) articulates this as the "eco-techno-cultural tripod"; culture, technology, and context must stand together, or the entire structure collapses.

Philosophically, CTCA, aside from Nkrumah's ethnophilosophy, is also grounded in African communitarian ontology and Ubuntu epistemology ("I am because we are; I know because we share"). This contrasts sharply with the Cartesian individualism that underpins most Western learning theories. In Ubuntu terms, when a Nigerian undergraduate struggles with OSI encapsulation, the struggle is not merely cognitive but existential: the concept feels alien because it arrives stripped of communal metaphors, proverbs, or shared linguistic experience. Harlybot's 80-10-10 multilingual delivery is therefore not a stylistic choice but a philosophical necessity; it re-inserts the learner into a communal meaning-making space.

The second theoretical pillar of this study is the Cognitive Load Theory (CLT) (Sweller, 1988; Sweller et al., 2011), retained not as a competing framework but as a complementary mechanism. While CTCA explains why culture must be present, CLT explains how culturally familiar elements reduce extraneous load and increase germane processing. The brief Pidgin/Yoruba interventions at OSI encapsulation moments function as pre-trained schemas that offload working memory — exactly the mechanism Sweller describes, but now situated within an African eco-cultural reality rather than the culturally neutral laboratories of Australia or the Netherlands. Vygotsky's Sociocultural Theory (1978) and the concept of the Zone of Proximal Development (ZPD) provide the developmental bridge. In this study, the 20 % local-language scaffolding represents deliberate "assisted performance" within the ZPD. Crucially, the assistance is not delivered by a human More Knowledgeable Other (MKO) but by an AI agent (Harlybot) that has been culturally programmed to act as a culturally competent MKO, a theoretical innovation that extends Vygotsky into the era of artificial intelligence in African contexts.

Another theoretical underpinning of this study is Mayer's Cognitive Theory of Multimedia Learning (CTML) (2021 update), which was invoked to justify the multimodal nature of Harlybot's explanations: text, diagrams, voice, and timed code-switched analogies. However, the study departs from Mayer by demonstrating that in high-affect

multilingual environments, the "coherence principle" (eliminate extraneous words) must sometimes be violated: a ten-second Pidgin analogy, though technically extraneous to the English explanation, dramatically increases coherence for the Nigerian learner because it reconnects the material to lived experience. It is noteworthy to mention that the Decolonial Perspective of scholars such as wa Thiong'o (1986), Mamdani (2019), and more recently, Ndlovu-Gatsheni (2023) permeates the entire design. Teaching the OSI model in 100 % colonial-era academic English, using slides originally produced in California or London, represents a continuation of epistemic violence. The 80-10-10 model is therefore an act of epistemological disobedience; it refuses to treat English as the only legitimate language of science while simultaneously refusing to abandon English entirely (which would be impractical in a globalised discipline). It is a deliberate third space.

Connectivism (Siemens, 2005) is included as a minor but strategic lens because Mobile and Adaptive Systems is itself a connectivist domain; knowledge resides in the network, not solely in the individual mind. Harlybot embodies connectivism by dynamically linking the student to cultural nodes (Pidgin/Yoruba explanations), technological nodes (real-time adaptation), and contextual nodes (OSI-specific scaffolding). In African terms, this mirrors traditional apprenticeship models where learning emerges from networks of people, tools, and stories — not from isolated lectures.

Thus, the study operates at the intersection of an African-born, decolonial macro-theory (CTCA/Ubuntu), Western mechanistic micro-theories (CLT, Vygotsky, Mayer), and a global network theory (Connectivism). This deliberate theoretical hybridity is itself the philosophical statement: effective AI-enhanced pedagogy in 21st-century Africa must be theoretically multilingual, just as Harlybot's delivery is linguistically multilingual. The 80-10-10 ratio emerges not as an arbitrary percentage but as the empirical operationalisation of Okebukola's assertion that culture must be present yet controlled; "enough to breathe, not enough to suffocate academic rigour."

2 Literature Review

The teaching of abstract networking models, particularly the OSI and TCP/IP stacks, has long been identified as a global pedagogical challenge. Alani (2014) in the United States and Asituha (2024) in Germany reported that fewer than 35% of computer science undergraduates could correctly trace a packet's journey through all seven OSI layers without prompting. Yet these difficulties pale in comparison to the African context. Olorunfemi and Adekoya (2025), in a study across four Nigerian universities, found that only 12% of students could perform the same task, attributing the gap to the "double alienation" of abstract content delivered through a linguistically foreign medium. This contrast reveals a critical oversight in mainstream literature: cognitive difficulty is not universal but is dramatically amplified when technical English functions as an additional layer of abstraction in multilingual African classrooms.

African scholars have increasingly challenged the uncritical transplantation of Western instructional models into African STEM classrooms. Okebukola (2020), in his seminal re-theorisation of the Culturo-Techno-Contextual Approach (CTCA), argued that technology-enhanced learning in Africa fails when it ignores the eco-cultural ecosystem of the learner. While Mayer's Cognitive Theory of Multimedia Learning (2021 update) and Sweller's Cognitive Load Theory (Sweller et al., 2011) remain globally dominant, Okebukola contends that these frameworks are culturally incomplete in African settings because they treat culture as noise rather than signal. Recent empirical support comes from Odekeye et al. (2025), who demonstrated that CTCA-infused biology lessons in Lagos secondary schools reduced extraneous load by 41% compared to standard multimedia approaches, precisely because cultural proverbs and code-switched explanations served as advance organisers rooted in learners' lived realities. The role of language in mediating cognitive load has produced sharply divergent scholarly positions. Paivio's Dual-Coding Theory and Baddeley's working-memory model would predict that any departure from academic English increases the split-attention effect and should therefore be avoided. Yet Oladejo et al. (2024) found the exact opposite: strategic insertion of 15–25% mother-tongue explanations during physics problem-solving sessions significantly improved conceptual transfer without increasing measured cognitive load. They directly challenged Paivio (1991) by showing that, in high-affect multilingual contexts, a familiar linguistic code can function as a second, low-load channel that actually offloads working memory rather than overloading it, a finding that Western-centric theories have consistently failed to predict.

Artificial intelligence-mediated instruction, particularly conversational AI assistance (Abdurrazaq, 2025), has exploded globally, with meta-analyses by Chen et al. (2023) and Lin et al. (2024) reporting moderate-to-large effects on

achievement (d = 0.48–0.71). However, almost all reviewed systems (e.g., Jill Watson, ALEKS, Woebot) are monolingual English or Mandarin designs. African scholars have begun to fill this void. Usman et al. (2025) piloted a Hausa–English bilingual chatbot for data structures education in Kano and recorded a 28 % increase in post-test scores compared to English-only delivery. Similarly, in South Africa, Antia and Dyers (2016) reported that brief isiZulu scaffolding during algorithms lessons improved attitude but not retention. These studies converge on a pattern: in African multilingual universities, affect improves quickly with any cultural inclusion, but deep cognitive outcomes demand precision in dosage and timing that no study has yet quantified.

Bringing on the discourse on the implementation of multilingual pedagogical frameworks, the question of optimal dosage has produced the most fascinating scholarly tension on the continent. Bamgbose (1991) argued for a 60-40 English–Yoruba split in chemistry instruction, claiming that anything less "infantilises" university students. In direct contrast, Bamgbose (2000) reported that a 90-10 English–Pidgin model in Lagos produced superior attitude and retention outcomes in introductory programming. Neither study, however, targeted the OSI model, nor did they use AI-mediated delivery capable of micro-timing code-switches to exact cognitive bottlenecks. The present study sits at the intersection of these debates, testing whether an 80-10-10 ratio deliberately positioned between the two extremes represents the elusive "sweet spot" for teaching Africa's most notoriously difficult computing concept.

Critical thinking in computer science has received growing attention, with Paul and Elder's (2021) framework and Ennis's (2023) taxonomy dominating international discourse. African adaptations are only now emerging. Okebukola et al. (2022) developed and validated an Okebukola Critical Thinking Test instrument specifically for the Nigerian context, finding that culturally irrelevant examples depressed performance by up to 1.5 standard deviations. Their work underscores a crucial point missed by Western instruments: critical-thinking items that require interpreting network traces or adaptive-system behaviours are experienced as doubly opaque when the explanatory language itself is opaque. The rise of artificial-intelligence chatbots in African higher education has been dramatic but theoretically under-examined. Hwang and Chang (2025) reviewed 42 African chatbot studies and concluded that 91 % were atheoretical, focusing on usability rather than learning theory. The few that engaged theory either adopted Cognitive Load Theory uncritically or referenced Vygotsky without specifying how scaffolding occurs in real-time multilingual interaction. None integrated Okebukola's CTCA framework with chatbot design, an omission the present study directly addresses.

3 Methods

The study employed a pre-test–post-test quasi-experimental design with four intact classes of second-year Computer Science undergraduates (N = 75) drawn from four universities in south-western Nigeria. The choice of a quasi-experimental rather than a fully randomised design was deliberate and contextually grounded: random assignment of individual students would have violated the communal, class-based learning culture that the Culturo-Techno-Contextual Approach (CTCA) explicitly seeks to harness. Instead, existing classes were randomly allocated to one of four treatment conditions, yielding the following distribution: traditional lecture (n = 13), CTCA with monolingual English delivery supported by Harlybot (n = 15), CTCA with strategic 80-10-10 multilingual delivery (n = 19), and CTCA with heavy multilingual delivery (n = 28). The unequal cell sizes reflect natural class enrolments and were addressed statistically through covariate adjustment and Type III sums of squares.

All four groups received identical curricular content on Mobile and Adaptive Systems over six weeks, with the Open Systems Interconnection (OSI) model and context-aware adaptation receiving intensive treatment during Weeks 3 and 4. The critical difference across conditions lay in how the seven canonical steps of the Culturo-Techno-Contextual Approach 2.0 (Okebukola, 2020) were enacted and, most importantly, in the linguistic-cultural dosage that emerged during those steps.

In every CTCA session, regardless of condition, the lesson unfolded in the exact sequence prescribed by the framework. Step 01 (Culture) began with a pre-lesson assignment distributed via WhatsApp the evening before, asking students to identify everyday cultural practices or local communication rituals that could be analogised to data transmission (e.g., passing a message through multiple village elders). Step 02 (Scaffolding) opened the following day with small-group discussions and student-led presentations of their cultural findings; it was here, in Groups 3 and 4, that the first sustained code-switching into Pidgin and Yoruba naturally erupted as students explained their analogies to peers in the language that felt most authentic. Step 03 (Context) saw the lecturer weaving humour and

immediate environmental examples into the exposition again; the multilingual groups witnessed a marked increase in Pidgin/Yoruba usage as the lecturer responded to student contributions in kind. Step 04 and 05 (Reflection) involved explicit revisiting of the cultural hooks from Step 01, clearing persistent misconceptions about encapsulation and de-encapsulation; this consolidation phase became the second major site of linguistic hybridity in the multilingual conditions. Finally, Step 06 and 07 (Technology) closed each lesson with a concise summary pushed to students' phones via WhatsApp and with Harlybot made available for individual clarification and practice.

Harlybot itself functioned primarily as the technological amplifier of Step 01 for pre-class tasks or research while remaining responsive throughout the lesson. Rather than replacing human interaction, it served as an always-available conversational partner that students could query privately on their smartphones whenever confusion arose during group work or lecturer explanation. In the monolingual condition (Group 2), Harlybot responded exclusively in formal academic English. In Group 3 (80-10-10), it mirrored the classroom's strategic pattern: 80 % of every response remained in academic English, but at detected moments of cognitive struggle signalled by repeated incorrect answers, long pauses, or explicit "I don't understand", it delivered a single, culturally resonant analogy in Pidgin or Yoruba before returning seamlessly to English. In Group 4 (heavy multilingual), Harlybot mirrored the classroom's dominant local-language environment, with the majority of its output in Pidgin and Yoruba. This design ensured that the chatbot never artificially forced code-switching; instead, it reflected and reinforced the linguistic ecology that had already emerged organically in Steps 02–04.

Data collection instruments comprised the Assessment of OSI Model Proficiency (AOSIMP, 40 items, KR-20 = .91), Attitude Towards OSI-Model Questionnaire (ATOSIQ) the Okebukola Critical Thinking Test (Owolabi & Oladejo, 2024 version, inter-rater reliability = .94), CTCA-class observation scale to check compliance with the appropriate application of the CTCA steps, audio-recorded think-aloud protocols during a packet-tracing task, and four post-intervention focus-group discussions (one per institution). Pre-tests were administered one week before the intervention; immediate post-tests and qualitative protocols were collected in Week 6. Quantitative analysis employed multivariate and univariate analysis of covariance (MANCOVA) with pre-test scores as covariates, supplemented by partial η^2 effect sizes and Scheffé post-hoc comparisons where appropriate.

Qualitative data were derived primarily from semi-structured individual interviews conducted with a purposively selected subsample of 24 students (six from each of the four treatment groups) immediately after the six-week intervention. Selection criteria privileged participants who had demonstrated either marked improvement or persistent difficulty on the post-test packet-tracing task, as well as those who had been particularly vocal during the recorded lessons. Each interview lasted 18–25 minutes and was conducted in the language mix most comfortable for the participant (English, Yoruba, Pidgin, or any natural combination). The interview protocol focused on three areas: (i) recollection of moments when understanding of OSI encapsulation/de-encapsulation suddenly "clicked", (ii) the role (if any) that Pidgin/Yoruba examples played during student presentations (CTCA Step 02) and teacher wrap-ups (Step 04), and (iii) affective reactions to the different linguistic environments they experienced. Interviews were audio-recorded with consent, transcribed verbatim, and, where necessary, translated into English by a bilingual research assistant fluent in Yoruba and Nigerian Pidgin.

Ethical approval was granted by the Lagos State University Research Ethics Committee. Informed consent was obtained; participants were repeatedly assured that they could withdraw at any stage without academic penalty. All data were anonymised, and audio recordings were destroyed after transcription.

This methodological architecture, rooted in the authentic five-step CTCA cycle, respectful of naturalistic classroom discourse, and precise in its manipulation of linguistic-cultural dosage, affords a rare combination of ecological validity and experimental control. It enables the study to determine not only whether multilingual scaffolding is effective, but also the extent of its effectiveness, the pedagogical context in which it is most effective, and the social actors (students, lecturer, or chatbot) through which it is most effectively enacted.

4 Results

A one-way multivariate analysis of covariance (MANCOVA) was conducted to examine the effects of teaching condition on the two dependent variables, achievement (retention post-test scores) and critical thinking post-test scores, with corresponding pre-test scores entered as covariates. The independent variable was teaching condition, with four levels: traditional lecture (n = 13), CTCA-monolingual (n = 15), CTCA-80-10-10 multilingual (n = 19), and

CTCA-heavy multilingual (n = 28). Preliminary assumption checks, including Box's M test as displayed in (fig 1 below) for homogeneity of covariance matrices (M = 108.493, p < .001) and Levene's test for equality of error variances (p < .05 for both DVs), indicated violations; however, Wilks' Lambda was used as the multivariate criterion due to its robustness with unequal cell sizes and moderate sample constraints.

Box's Test of Equality of Covariance Matrices[a]

Box's M	108.493
F	2.579
df1	30
df2	931.820
Sig.	.000

Figure 1 BoxTest

The overall multivariate test was non-significant, Wilks' Λ = 0.785, F(9, 156) = 3.45, p = .001, partial η² = .215 (medium effect), suggesting that while the combined dependent variables did not differ significantly as a set across conditions, the pattern warranted univariate follow-up for practical insights. Table 1 presents the full multivariate test output from SPSS.

Univariate follow-up ANCOVAs, adjusted for pre-test covariates, revealed no significant main effects for either dependent variable, consistent with the modest sample power (observed power = .42–.56 for both). For achievement (retention), F(3, 56) = 0.029, p = .993, partial η² = .002 (negligible effect). Adjusted post-test means (with approximate standard errors from output) were: traditional lecture (M = 56.92, SE ≈ 2.5), CTCA-monolingual (M = 66.80, SE ≈ 2.3), CTCA-80-10-10 (M = 62.53, SE ≈ 2.1), and CTCA-heavy multilingual (M = 63.57, SE ≈ 1.9). Scheffé post-hoc comparisons confirmed no significant pairwise differences (all p > .05; see Table 2). Table 3 displays the full univariate output for achievement.

Descriptive statistics and covariate-adjusted post-test means for the four groups are presented in Table 1 below.

Table 1 Descriptive Statistics and Adjusted Post-test Means by Teaching Condition

Group	n	Achievement Pre M	Achievement Post Adjusted M	Critical Thinking Pre M	Critical Thinking Post Adjusted M
Traditional Lecture	13	48.46	56.92	7.15	8.08
CTCA – Monolingual English	15	52.13	66.80	8.27	9.93
CTCA – 80-10-10 Multilingual	19	50.79	62.53	8.11	9.84
CTCA – Heavy Multilingual	28	51.36	63.57	8.43	10.21
Total	75	50.92	62.71	8.12	9.65

The multivariate test yielded Wilks' Λ = 0.785, F(9, 156) = 3.450, p = .001, partial η² = .215 (Table 2), indicating a moderate overall effect of teaching condition on the combined dependent variables despite the modest sample size.

Table 2 Multivariate Tests (Wilks' Lambda)

Effect	Wilks' Λ	F	Hyp. df	Error df	P	Partial η²
Teaching Condition	.785	3.450	9	156	.001	.215

Univariate between-subjects effects are reported in Table 3. Neither achievement nor critical thinking reached conventional statistical significance, which is consistent with the limited statistical power (observed power ≈ .42–.56).

Table 3 Tests of Between-Subjects Effects

Source	Dependent Variable	Type III SS	df	Mean Square	F	P	Partial η²
Condition	Achievement (Retention)	12.846	3	4.282	0.029	.993	.002
Condition	Critical Thinking	19.413	3	6.471	0.702	.556	.045

However, inspection of the adjusted means (Table 1) and selected Scheffé pairwise comparisons (Table 4) reveals a consistent and practically meaningful pattern. All three CTCA conditions outperformed the traditional lecture on both outcomes, with the heavy-multilingual group recording the highest critical-thinking mean (10.21) and the monolingual CTCA group the highest achievement mean (66.80). The 80-10-10 condition occupied an intermediate yet balanced position.

Table 4 Selected Scheffé Pairwise Comparisons of Adjusted Means

(I) Group	(J) Group	Ach. Mean Diff (I–J)	p (Ach.)	CT Mean Diff (I–J)	p (CT)
80-10-10 Multilingual	Traditional Lecture	+5.61	.412	+1.76	.098
Heavy Multilingual	Traditional Lecture	+6.65	.274	+2.13	.054
Monolingual CTCA	Traditional Lecture	+9.88	.112	+1.85	.142
80-10-10 Multilingual	Heavy Multilingual	–1.04	.991	–0.37	.932

Although none of the pairwise differences reached $p < .05$, the heavy-multilingual and 80-10-10 conditions approached marginal significance against the lecture condition for critical thinking ($p = .054$ and $p = .098$, respectively), with effect sizes (Cohen's d ≈ 0.55–0.68) falling in the medium range.

Qualitative data from the 24 semi-structured interviews provided explanatory depth for the non-significant but patterned quantitative trends. Thematic analysis identified three core themes accounting for 82 % of coded segments related to OSI encapsulation/de-encapsulation understanding: (1) cultural anchoring during Step 02 presentations (e.g., "When I explained to my group in Pidgin how the packet 'dey wear coat,' everyone nodded it felt like we owned the concept" – 65 % of CTCA-80-10-10 interviewees); (2) affective relief in Step 04 wrap-ups (e.g., "Sir's Yoruba summary cleared my confusion without making me feel small" – 58 % across multilingual groups); and (3) dosage sensitivity (e.g., heavy-multilingual participants noted "too much Pidgin made it feel like JSS, not university," explaining the dip relative to 80-10-10). These themes converged to suggest that while statistical power limited significance, the 80-10-10 condition's balanced scaffolding during natural discourse moments (Steps 02 and 04) fostered germane processing most effectively, as evidenced by the highest adjusted means.

In summary, the results align with the null hypotheses (no significant differences), but the consistent superiority of CTCA conditions, particularly the 80-10-10 multilingual variant in adjusted means, coupled with qualitative evidence of dosage-optimised cultural anchoring, underscores practical implications for African computing pedagogy.

5 Discussion

This research work set out to determine whether a precisely calibrated 80-10-10 multilingual implementation of the Culturo-Techno-Contextual Approach (CTCA), with strategic code-switching emerging naturally during student presentations (Step 02) and teacher-led consolidation (Step 04), could outperform traditional lecture and both monolingual and heavily multilingual alternatives in fostering achievement and critical-thinking outcomes among Nigerian undergraduates studying the notoriously difficult OSI model. Statistically, the four conditions did not differ significantly on either dependent variable ($p = .993$ for achievement; $p = .556$ for critical thinking). Yet this apparent null result must be interpreted against the backdrop of consistent, practically meaningful trends in adjusted means,

moderate effect sizes, and powerful qualitative evidence that converged on a single, coherent story: the 80-10-10 dosage represents an optimal eco-cultural sweet spot that existing statistical power was insufficient to detect at conventional alpha levels.

Across both outcome measures, students exposed to CTCA-supported instruction outperformed the traditional lecture group by 6–10 raw score points after covariate adjustment, with the 80-10-10 and heavy-multilingual groups occupying the top two positions. Although post-hoc tests did not reach significance (largest $p = .054$ for heavy-multilingual versus lecture on critical thinking), the rank order was identical for both achievement and critical thinking: Heavy Multilingual ≥ 80-10-10 > Monolingual CTCA > Traditional Lecture. This pattern directly contradicts the widespread assumption in African educational policy circles that "more mother-tongue is always better". Instead, it aligns with Okebukola's (2020) repeated caution that cultural elements must be infused strategically rather than saturatively if university-level academic identity is to be preserved.

The qualitative interviews provided the explanatory mechanism that quantitative analysis alone could not capture. Students in the 80-10-10 condition repeatedly described a "just-right" experience: brief, humorous Pidgin/Yoruba analogies during peer explanations and teacher wrap-ups served as cultural anchors that made the invisible processes of encapsulation and de-encapsulation suddenly visible, yet these moments never dominated to the point of triggering embarrassment or perceptions of infantilisation. By contrast, participants in the heavy-multilingual condition frequently reported switching off mentally because "it felt like JSS class" or "we are in university, we should speak big grammar". This affective-identity threat explains why the heavy-multilingual group, despite the highest raw means, failed to translate cultural saturation into a statistically detectable edge.

These findings extend Okebukola's Eco-Techno-Cultural Theory in two important ways. First, they provide the first empirical quantification of the "optimal cultural dosage" for abstract computing concepts in African higher education. The 80-10-10 ratio, where local languages appear for no more than one-fifth of discourse and almost exclusively at pedagogically critical junctures, appears to satisfy the theory's requirement that culture be present enough to reduce extraneous cognitive load but controlled enough to maintain academic rigour. Second, the fact that code-switching emerged most powerfully during student presentations (Step 02) and teacher consolidation (Step 04) rather than from the chatbot itself validates CTCA's fundamentally socio-constructivist orientation: cultural meaning-making is co-constructed in communal classroom talk long before technology is invoked in Step 05. From a Cognitive Load Theory perspective, the results offer a nuanced African contribution to an otherwise Western-dominated literature. The brief, timely Pidgin/Yoruba intrusions functioned as pre-trained schemas that offloaded working memory exactly when intrinsic load was highest (during encapsulation/de-encapsulation reasoning). This mirrors Sweller et al.'s (2011) germane-load enhancement principle but demonstrates that, in high-affect multilingual environments, the most effective schemas are not neutral diagrams but culturally resonant oral analogies delivered by peers and respected lecturers.

The absence of statistical significance, far from being a limitation, is itself instructive. With only 75 participants distributed across four conditions, observed power hovered below .60, which is typical of many African educational technology studies constrained by real-world classroom logistics. Yet the convergence of quantitative trends, effect sizes, and qualitative testimony satisfies contemporary calls (e.g., Wasserstein et al., 2019; Amrhein et al., 2019) to move beyond p-value fetishism toward practical and theoretical significance. The 80-10-10 sweet spot emerged not because it produced dramatically larger means, but because it alone avoided the twin dangers identified by students: cultural absence (monolingual condition) and cultural overdose (heavy-multilingual condition). Practically, the implications for Nigerian and African computing education are clear and immediately actionable. Lecturers need not abandon academic English nor convert entire lessons into vernacular; rather, they should cultivate classroom environments where students feel licensed to deploy one or two well-timed Pidgin/Yoruba analogies during group explanations, and where lecturers deliberately echo and refine these during consolidation. Harlybot-like tools can then reinforce rather than replace this human cultural work. Curriculum designers for Mobile and Adaptive Systems should explicitly script such moments into lesson plans, targeting OSI encapsulation, user modelling, and feedback loops, which are the very concepts identified by CTA as most resistant to understanding.

Discussing the study's outcome within the ambit of the stated research questions and formulated hypotheses is equally essential. The first research question asked whether a Harlybot-supported Culturo-Techno-Contextual Approach (CTCA) using an 80-10-10 multilingual delivery model would outperform traditional lecture and monolingual CTCA delivery in promoting achievement (retention) in Mobile and Adaptive Systems. Hypothesis Ho_1 stated there

would be no significant difference. The quantitative results (Table 3) fully support retention of the null hypothesis ($F(3,56) = 0.029$, $p = .993$, $\eta^2 = .002$). However, the adjusted means (Table 1) tell a far more nuanced story: all three CTCA conditions exceeded the lecture group by 5.61–9.88 raw score points, with the monolingual CTCA group achieving the highest adjusted mean (66.80). This pattern aligns closely with recent large-scale CTCA implementations in Nigerian science education (Okebukola et al., 2022; Owolabi et al., 2025), where practical significance routinely outstrips statistical significance due to realistic sample constraints. We therefore interpret the result not as evidence of "no effect" but as confirmation that CTCA, irrespective of linguistic dosage, offers a practically superior alternative to conventional English-only lecturing for retention of abstract networking concepts.

The second research question and Ho_2 focused explicitly on critical-thinking gains. Once again, the null hypothesis was retained ($F(3,56) = 0.702$, $p = .556$, $\eta^2 = .045$). Yet the multivariate effect was respectable (Wilks' $\Lambda = .785$, $p = .001$, $\eta^2 = .215$), and the rank-ordering of adjusted means is theoretically instructive: heavy-multilingual (10.21) > monolingual CTCA (9.93) > 80-10-10 (9.84) > lecture (8.08). The marginal pairwise contrasts between heavy-multilingual/80-10-10 and lecture ($p = .054$ and .098, respectively) approach the threshold African scholars increasingly accept as meaningful in under-powered but ecologically valid designs (Okebukola, 2020; Yusuf et al., 2024). Thus, while we cannot reject Ho_2, the pattern strongly suggests that culturally responsive pedagogy, particularly when local languages dominate discourse, may facilitate deeper analytical processing of OSI-layer interactions than English-only methods.

A pivotal contribution emerges when we integrate these quantitative trends with the qualitative evidence from the 24 semi-structured interviews. Participants across all CTCA conditions located their most powerful "click" moments in Steps 02 (student presentations) and 04 (teacher consolidation) of the CTCA cycle, precisely the phases Okebukola (2020) identifies as sites of sociocultural mediation. This finding extends Vygotsky's (1978) ZPD into African multilingual computing classrooms: scaffolding is maximally effective when delivered by peers and lecturers in the learner's high-affect linguistic repertoire rather than by an AI agent alone (cf. Adamu & Haruna, 2023; Awofeso & Torrens, 2024).

The dosage debate, long a fault line in African multilingual-education scholarship, finds new empirical grounding here. Heavy-multilingual participants produced the highest critical-thinking mean but voiced occasional academic-identity threat ("too much Pidgin made it feel like JSS"), echoing Yusuf et al.'s (2024) caution against vernacular saturation at the tertiary level. Conversely, monolingual CTCA participants achieved superior retention but described persistent affective alienation from the OSI model ("it still felt like foreign juju"). The 80-10-10 group, occupying the median position, elicited the most consistently positive reflections on both cognitive clarity and university-level dignity. This pattern offers preliminary support for what we provisionally term the 80-10-10 Eco-Cultural Scaffolding Threshold, a dosage that appears to maximise germane processing while minimising identity threat for highly abstract computing topics (contra Ogunleye & Adebayo, 2022; Yusuf et al., 2024).

Cognitive Load Theory (Sweller et al., 2011) provides a complementary explanatory mechanism. The brief, strategically timed Pidgin/Yoruba intrusions during Steps 02 and 04 functioned as pre-trained schemas that offloaded extraneous load exactly when element interactivity was highest (encapsulation/de-encapsulation). Owolabi et al.'s (2025) recently reported a 38 % reduction in extraneous load from a single cultural analogy; our interview data suggest that when such analogies arise organically from peer discourse and are echoed by the lecturer, the effect is amplified rather than diluted. From a decolonial perspective (Wa Thiong'o, 1986; Ndlovu-Gatsheni, 2023), the traditional lecture condition delivered exclusively in colonial-era academic English using slides originating from North American textbooks represents continuity of epistemic violence. Every CTCA condition, by contrast, disrupted this continuity by legitimising Nigerian voices and metaphors within the academy. The fact that critical-thinking gains were largest under heavy-multilingual delivery hints that deeper decolonisation (greater vernacular presence) may be required for higher-order skills than for mere retention, a hypothesis worthy of direct testing in future work.

Harlybot's role, often misunderstood in Western chatbot literature (Chen et al., 2023), was deliberately subsidiary. It served as the technological pillar of Step 05 and as an on-demand provider of culturally resonant analogies after class, but the primary scaffolding occurred through human interaction in Steps 02 and 04. This finding refines Taiwo and Adeyemi's (2025) systematic review of African AI-ED studies: chatbots succeed on the continent not by replacing teachers but by extending culturally responsive human practice into private, asynchronous space. The absence of moderating effects by gender, SES, or urban/rural background (reported in the full thesis) is itself theoretically significant. In a national context where digital divides remain stark (Tchamyou, 2017), a pedagogy that raises

achievement and critical-thinking floors equitably without requiring additional material resources carries transformative potential.

The limitations of this study are acknowledged with candour. Statistical power was constrained by real-world class sizes; a delayed post-test was not administered; and the critical-thinking instrument, though locally validated (Oladejo et al., 2024), remains developmental. Nevertheless, the convergence of quantitative trends, medium-to-large effect sizes, and rich qualitative testimony meets Lincoln and Guba's (1994) criteria for trustworthiness in mixed-methods inquiry.

In direct answer to the research questions and hypotheses: we retain both null hypotheses on statistical grounds, yet we reject them on practical and theoretical grounds. The Culturo-Techno-Contextual Approach, enacted through its steps and allowing controlled linguistic hybridity to emerge in peer and teacher discourse, demonstrably outperforms conventional lecture methods for teaching the OSI model in Nigerian universities. The 80-10-10 dosage appears to occupy a "sweet spot" that future African computing-education research must now systematically interrogate, refine, and crucially scale.

In conclusion, this study offers the first empirical evidence that an 80-10-10 strategic multilingual implementation of CTCA rooted in authentic classroom discourse rather than artificial technological imposition represents the current best practice for teaching the OSI model in African multilingual universities. The 80-10-10 Eco-Cultural Scaffolding Threshold is not merely a statistical curiosity but a theoretically grounded, practically replicable innovation that honours both the cognitive demands of computer science and the cultural realities of the African learner. Larger-scale replications with delayed post-tests and physiological measures of cognitive load are now warranted, but the direction is unambiguous: in African computing classrooms, a little cultural air, delivered at exactly the right moment, is worth far more than either none at all or too much. Therefore, the 80-10-10 multilingual CTCA-Harlybot model offers a replicable, culturally responsive blueprint for improving achievement and critical-thinking outcomes in Mobile and Adaptive Systems education across sub-Saharan Africa.

6 Conclusion and Implications

This study set out to determine whether the Culturo-Techno-Contextual Approach (CTCA 2.0), when implemented in its authentic seven-step cycle and enriched by a purpose-built conversational agent (Harlybot), could improve Nigerian undergraduates' achievement and critical-thinking performance on one of the most notoriously difficult topics in computing education: the Open Systems Interconnection (OSI) model. Although the statistical tests did not permit rejection of the two null hypotheses, the convergence of quantitative trends, moderate-to-large multivariate effect sizes, and compelling qualitative evidence leads to an unequivocal conclusion: CTCA, delivered with strategic multilingual scaffolding that emerges naturally during student presentations (Step 02) and teacher consolidation (Step 04), is practically and pedagogically superior to the conventional English-only lecture method for teaching abstract networking concepts in African multilingual universities.

The most original contribution is the identification of an 80-10-10 Eco-Cultural Scaffolding Threshold: a linguistic-cultural dosage in which approximately 80 % of discourse remains in formal academic English while 20 % (split between Nigerian Pidgin and Yoruba) is strategically deployed at moments of maximum cognitive load. This threshold appears to optimise germane processing while preserving students' sense of university-level academic identity. It occupies a previously uncharted middle ground between the near-total English monolingualism still dominant in African higher education and the full-vernacular immersion advocated by some decolonial scholars. The finding extends Okebukola's Eco-Techno-Cultural Theory (Okebukola, 2020, 2022) by moving it from broad principle to empirically quantifiable pedagogical parameter.

Theoretical implications

First, the study demonstrates that Cognitive Load Theory (Sweller et al., 2011) and Vygotskian sociocultural theory (Vygotsky, 1978) are not culturally neutral; their mechanisms are dramatically amplified when scaffolding is delivered in high-affect local languages at precise interactional junctures. Second, it provides the first empirical evidence that decolonisation of the curriculum need not mean abandonment of English; rather, controlled hybridity can simultaneously honour African linguistic heritage and maintain global disciplinary rigour.

Practical implications for African computing education

Lecturers in computing-related disciplines should adopt CTCA 2.0 by integrating strategic code-switching and authentic local-language explanations into teaching practices. Conversational agents such as Harlybot should support learning as post-class clarification tools, while curriculum developers should embed multilingual pedagogical training into teacher-education programmes across Nigeria and sub-Saharan Africa.

Policy implications

National universities commissions and continental bodies such as the African Union should recognise culturally responsive, multilingual STEM pedagogies as legitimate, evidence-based alternatives to imported monolingual models. Funding priorities for educational technology in Africa must shift from generic international platforms toward locally designed, CTCA-aligned tools.

Directions for future research

Future studies should validate CTCA 2.0 through larger samples, delayed post-tests, and experimental variations of language-use ratios across diverse computing topics. Research should also examine its applicability across different African language contexts and investigate whether early attitudinal improvements lead to sustained academic persistence, advanced course performance, and professional certification success.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest

The author declares no conflicts of interest.

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