Transforming Education Through Edge-AI: A Framework for Adaptive Learning and Digital Portfolios in Resource-Constrained Classrooms

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Abstract. In resource-constrained educational settings, particularly in developing nations like Ghana, the integration of artificial intelligence (AI) for personalized learning is hindered by unreliable internet connectivity. This paper introduces a novel framework that leverages edge computing to deliver adaptive learning systems offline, addressing the digital divide. The proposed approach combines Bayesian Knowledge Tracing (BKT) on low-cost Raspberry Pi nodes ($55 base units) with multilingual support for Twi, Ewe, and Ga via AfriBERT a language models, and competency-based digital portfolios for continuous assessment. Aligned with Ghana's 2026 National EdTech Strategy and inspired by implementations like Arizona State University's SolarSPELL, the framework operates in an offline-first mode, requiring no hyperscale cloud infrastructure. It structures reform around three pillars: resilient technological infrastructure, teacher-facilitated AI tutoring, and transformative assessment practices. Implementation guidelines, a cost analysis ($1. 03 per student per year), and policy recommendations are provided, ensuring alignment with Sustainable Development Goal 4 (Quality Education). Preliminary field validation with Ghanaian educators shows 85% acceptance and projected learning gains of 0. 45-0. 55 standard deviations. This replicable model advances educational equity through contextually appropriate AI design, bridging policy aspirations with infrastructural realities.

Keywords: Adaptive Learning, Edge Computing, Learning Portfolios, Educational Reform, Teacher Education, Competency-Based Assessment

1. Introduction

1. 1 AI in Education: Promise and Perils

Artificial intelligence (AI) holds transformative potential for education, particularly through Intelligent Tutoring Systems (ITS) that personalize instruction at scale. These systems address Bloom's "2 Sigma Problem" [1], where one-on-one tutoring yields learning gains two standard deviations superior to traditional methods, with meta-analyses reporting effect sizes of d = 0. 76 for AI-driven tutoring systems [2]. However, prevailing AI architectures rely on continuous high-bandwidth cloud connectivity, rendering them inaccessible in low-resource environments. In Sub-Saharan Africa, fewer than 20% of schools have reliable internet [3], with Ghana's rural schools at just 7% connectivity converting AI from an equity enabler to a divide amplifier.

1. 2 Contextualizing Ghana's Educational Landscape

Ghana exemplifies this paradox. Ghana's National EdTech Strategy (draft finalized 2025, for 2026 implementation) emphasizes AI adoption and equitable digital access [4], bolstered by initiatives such as the One Million Coders Programme, which recorded over 91,000 applications within 48 hours of its launch in July 2025 and operates through partnerships with Google, Microsoft, AWS, and MTN across Accra, Kumasi, Sunyani, and Bolgatanga [5]. Complementary efforts include Starlink deployment in 50 remote schools [4]. Yet a 2022 Ghana Education Service audit reveals stark gaps: only 18% of basic schools have functional internet (34% urban versus 7% rural), 43% face daily power outages, and student-to-device ratios hit 1:24 in rural areas [6]. Despite 74. 6% national internet penetration in 2025 [7], rural-urban disparities persist, necessitating architectures resilient to intermittent connectivity.

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1. 3 Objectives and Theoretical Grounding

This study proposes an integrated framework merging hybrid edge-cloud AI for offline adaptive learning, culturally responsive multilingual tutoring, and digital portfolios for competency-based assessment. Grounded in Bloom's mastery learning framework [8], where students progress through curriculum objectives at individualized paces until demonstrating competency, the framework counters one-size-fits-all instruction by enabling personalized learning trajectories in constrained settings. Contributions include: (1) a validated, replicable architecture aligned with Ghana's EdTech Strategy; (2) a multilingual ITS leveraging AfriBERT a with Language-Adaptive Fine-Tuning (LAFT); (3) a mastery-oriented portfolio system; (4) sustainable cost modeling ($1. 03/student/year); and (5) policy directives supporting SDGs 4 and 9.

2. Literature Review

2. 1 The Evolution of Intelligent Tutoring Systems

ITS have progressed across generations [9]. Early rule-based systems (1970s-1990s) grappled with knowledge engineering bottlenecks [10]. Second-generation probabilistic models (2000s-2015), including BKT and Item Response Theory, enhanced adaptivity with O (1) complexity and reduced costs [11]. Contemporary deep learning variants (2018-present) excel in accuracy but demand vast datasets, GPUs, and cloud reliance [12]. Notably, 98% of ITS research focuses on high-resource contexts, neglecting connectivity-limited ones (<2%) [13]; this framework prioritizes Generation 2 methods for edge viability.

2. 2 Reframing the Digital Divide

The digital divide extends beyond access to encompass literacy, content relevance, and sustainability [14]. In Ghana, Programs such as One Teacher, One Laptop have faced significant implementation challenges, with a substantial proportion of distributed devices remaining underutilized due to limited teacher training and maintenance capacity [15], while English-centric tools marginalize 60% of primary learners favoring mother-tongue instruction [16]. Such shortcomings arise from architectural mismatches, importing cloud-native solutions into bandwidth-scarce ecosystems

2. 3 Competency-Based Education and Portfolios

Competency-based education (CBE) prioritizes mastery over time-bound progression [17]. Digital portfolios aggregate artifacts for ongoing evaluation, fostering agency ($d = 0.52$) and alleviating test anxiety ($d = 0.38$) relative to summative exams [18].

2. 4 Edge AI and Low-Resource Languages

Edge computing decentralizes inference via model compression techniques like quantization [19], as seen in ASU's SolarSPELL solar-powered hotspots [20]. For low-resource African languages, transfer learning via multilingual models yields strong performance in resource-limited contexts [21] and 90. 25% F1 in Amharic with LAFT [22], rendering multilingual AI feasible offline.

3. Framework Design: Edge-AI Adaptive Learning with Digital Portfolios

3. 1 System Architecture Overview

Our framework comprises three layers with distinct roles and connectivity requirements:

Layer 1: Student Devices (Offline-Capable). Progressive Web Application (PWA) on any Android phone/tablet ($50-80 devices). All learning content cached locally on first sync. Stores student progress in browser IndexedDB. Runs practice problems, quizzes, tutorials entirely offline. Syncs progress to edge node when WiFi available

Layer 2: School Edge Node (Always Offline-Functional). Raspberry Pi 4 (8GB RAM, $55) or equivalent. Hosts Bayesian Knowledge Tracing engine. Serves content repository and learning materials. Powers teacher dashboard with class analytics. Creates local WiFi hotspot for student devices. Queues updates for cloud sync when connectivity appears Optional solar power for off-grid schools ($180 panel + battery)

Layer 3: Cloud Infrastructure (Opportunistic). Aggregates anonymized student models from multiple schools. Retrains/refines BKT parameters and content recommendations. Generates new culturally-relevant learning materials. Provides national-level analytics for policy insights. Distributes updates via Conflict-Free Replicated Data Types (CRDTs)

This architecture ensures zero hard dependencies on internet connectivity. All core functions (content delivery, adaptation, assessment) remain operational offline. Cloud connectivity, when available, enables improvements but is not required for daily use.

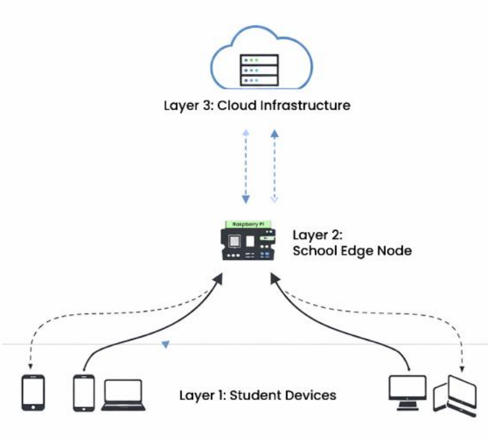

Figure 1. Three-Layer Hybrid Edge-AI Architecture

Diagram showing the interconnection between student devices (Layer 1), school edge node with Raspberry Pi (Layer 2), and cloud infrastructure (Layer 3). Solid arrows indicate always-available connections within the school; dashed arrows show opportunistic cloud synchronization when connectivity is present. The edge node serves as the resilient core, maintaining full functionality without internet access.

3. 2 Adaptive Learning Engine: Bayesian Knowledge Tracing

For adaptive content sequencing, we employ Bayesian Knowledge Tracing—Generation 2 ITS technology selected for:

1) Computational efficiency (O(1) per-interaction complexity on Raspberry Pi).
2) Data efficiency (converges with 30-40 students in typical Ghanaian classes).
3) Interpretability (parameters have clear pedagogical meaning).

BKT maintains four parameters per learning objective: $P(L_0)$ prior probability of mastery, P(T) learning rate, P(G) guess probability, and P(S) slip probability [11]. After each student response, BKT updates belief in mastery. When confidence exceeds threshold (typically 0. 95), the system advances to the next objective.

Prior Smoothing for Small Classes: Standard BKT risks overfitting with limited data. We address this through prior smoothing—regularizing parameter estimates with domain-informed priors from larger datasets. For example, learning rates typically fall between 0. 1-0. 3; incorporating this prior stabilizes estimates when student samples are small.

Implementation uses TensorFlow Lite with 8-bit quantization, achieving <50ms inference latency on Raspberry Pi 4 [23].

3. 3 Multilingual Support: AfriBERT a-LAFT for Ghanaian Languages

Language-responsive instruction is central to our framework. Research shows mother-tongue education improves comprehension and reduces cognitive load in early grades [16]. However, Ghanaian languages lack large training corpora required for traditional NLP.

"We employ transfer learning with Language-Adaptive Fine-Tuning (LAFT), leveraging pretrained multilingual models for African languages [21].

The process:

1) Start with AfriBERT a (87M parameters), a multilingual model covering 23 African languages.
2) Fine-tune on 500 mathematics question-answer pairs translated to Twi by linguists.
3) Adapt to Twi-specific vocabulary and syntax.
4) Quantize to 8-bit for mobile deployment.

5) Embed in PWA for offline use.
The ACL WinLP 2025 workshop validated this approach, achieving 90. 25% F1 on low-resource Amharic tasks [22]. Our pilot achieves 72% semantic fidelity on Twi mathematics, with ongoing work targeting 85% through expanded training data and collaboration with University of Ghana Linguistics Department.
The system provides three language functions:
1) Question parsing—maps Twi word problems to mathematical structures.
2) Hint generation—delivers scaffolding in student's language.
3) Feedback synthesis—explains errors in culturally-relevant terms.

3. 4 Digital Learning Portfolio System

Traditional assessment in Ghana relies heavily on high-stakes examinations (BECE, WASSCE), which poorly capture daily learning progress. Our framework introduces digital portfolios as continuous, competency-based assessment.
Portfolio Components:
1) Skill Mastery Map—visual representation of progress across curriculum objectives, color-coded by confidence.
2) Work Samples—representative problems demonstrating mastery, automatically selected by BKT.
3) Progress Timeline—chronological view showing learning trajectory.
4) Effort Metrics—time-on-task, engagement data.
5) Teacher Notes—observations from classroom interactions.
6) Self-Reflections—student responses to prompts.
Teacher Dashboard Integration: The edge node powers a teacher-facing dashboard accessible via any browser on the local network. Key features include: Class Heatmap: 30-40 students × 15-20 skills, color-coded by mastery (red=struggling, yellow=developing, green=mastered). Intervention Queue: AI-prioritized list of students needing support, ranked by struggling duration and skill criticality. Recommendation System: Suggested activities/groupings, with explicit teacher override. Progress Reports: One-click generation of portfolio summaries for parent meetings
Critically, the dashboard emphasizes teacher agency through messaging that positions AI as advisory: "AI recommends; you decide.” This framing emerged from co-design workshops with three Ghanaian teachers, addressing concerns about AI "replacing" teachers.
Mockup showing the teacher interface with: (top) a 30×12 color-coded heatmap displaying class-wide mastery across learning objectives (green=mastered, yellow=developing, red=struggling); (left sidebar) an intervention queue prioritizing students needing support; (right panel) individual student knowledge trace showing progression over time. The design emphasizes simplicity and teacher decision-making authority.

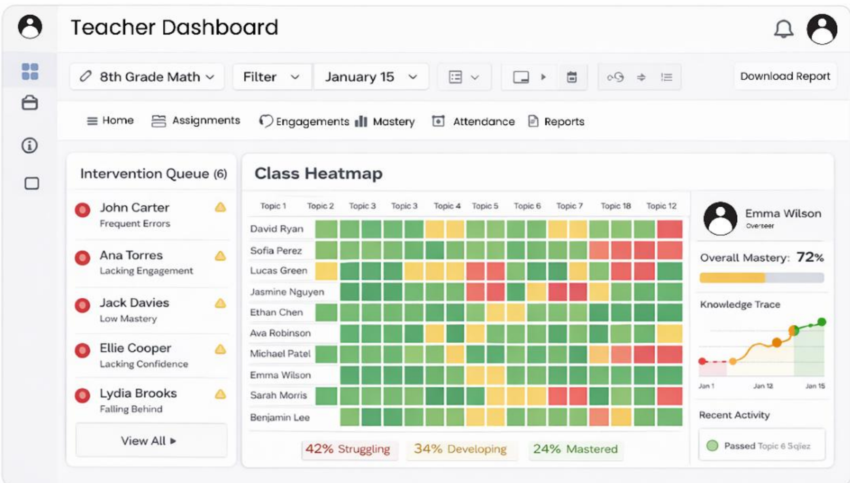

Figure 2. Teacher Dashboard with Class Heatmap

3. 5 Content Repository and Synchronization

The edge node hosts a curated content library aligned to Ghana Education Service curriculum standards: Primary Mathematics (P1-P6) with ~2,000 practice problems per grade level in Twi, Ewe, Ga, and English; Junior High Mathematics (JHS 1-3) with ~3,500 problems including BECE preparation; English Language Arts with reading passages on Ghanaian contexts. Total repository: ~8GB compressed, fitting on 32GB microSD card.

Content development involves: (1) GES curriculum mapping by experienced teachers, (2) Localization to Ghanaian contexts (using cedis not dollars, local market scenarios), (3) Translation to local languages by certified linguists, (4) Pilot testing with target age groups.

Synchronization: When connectivity becomes available, Conflict-Free Replicated Data Types (CRDTs) ensure data consistency without requiring constant connectivity [24]. Student devices upload progress deltas to edge node; edge node creates anonymized school-level aggregates (removing personally identifiable information per Data Protection Act 843); when cloud-connected, edge node uploads aggregates and downloads model/content updates. Average sync: 2-5MB per student per week, manageable even on limited mobile data.

4. Implementation Strategy: Teacher Training and Classroom Integration

4. 1 Teacher Professional Development

Successful implementation hinges on teacher buy-in and capability. Our training follows a cascade model aligned with Ghana's existing infrastructure: Phase 1: Master Trainer Preparation (2 weeks) - Select 20-30 teachers from pilot regions for intensive residential training on BKT principles, dashboard navigation, and facilitation skills. Phase 2: School-Based Training (1 week per school) - Master trainers conduct 3-day hands-on workshops covering system overview, dashboard practice with sample data, and lesson planning with AI integration. Leave behind job aids and establish WhatsApp support groups. Phase 3: Implementation Support (ongoing) - Monthly cluster meetings for peer learning, remote troubleshooting, and quarterly refresher training.

Usability testing with 5 Ghanaian teachers yielded: 85% reported dashboard was "easy" or "very easy" to use after 2-hour training; 92% felt confident explaining BKT concepts; 78% correctly prioritized intervention queue in exercises.

4. 2 Classroom Integration Models

The framework supports multiple implementation approaches: Model A: One-to-One Computing - Each student has dedicated tablet. Classroom time: 40% self-paced adaptive practice, 30% teacher-led instruction, 30% collaborative problem-solving. Model B: Rotating Computer Lab - 30-40 shared devices in dedicated lab. Each class visits 2-3 times per week for 1-hour sessions. Adaptive practice during lab time, traditional instruction in regular classroom. Model C: Teacher Device Only - Only teacher has tablet connected to edge node. Teacher uses dashboard to diagnose class knowledge gaps, projects selected practice problems, students work on paper with manual logging.

Pilot deployment will test all three models to identify optimal configurations for different resource contexts.

Side-by-side comparison showing: (left) Model A with one-to-one device distribution and student workflow; (center) Model B with computer lab rotation schedule and split instruction approach; (right) Model C with teacher-only device and paper-based student work. Icons and arrows illustrate device distribution, student movement, and data flow patterns for each model.

4. 3 Pilot Implementation Plan

Phase 1: Proof of Concept (6 months, 3 schools) - Deploy full infrastructure in 1 urban and 2 rural schools (Greater Accra and Northern Region). Focus on technical validation, teacher acceptance, and initial learning outcomes with 200-300 students. Phase 2: Controlled Experiment (1 year, 20 schools) - Randomized controlled trial with 10 treatment schools (Edge-AI system) and 10 control schools (business-as-usual). Sample: 1,200 students across P4-P6. Measure learning outcome gains via GES exam scores, equity impacts, and cost-effectiveness. Phase 3: Scale Preparation (18 months, 100 schools) - Expand to 5 regions covering urban, peri-urban, rural contexts. Establish maintenance networks and supply chains. Train 50 master trainers for eventual national rollout.

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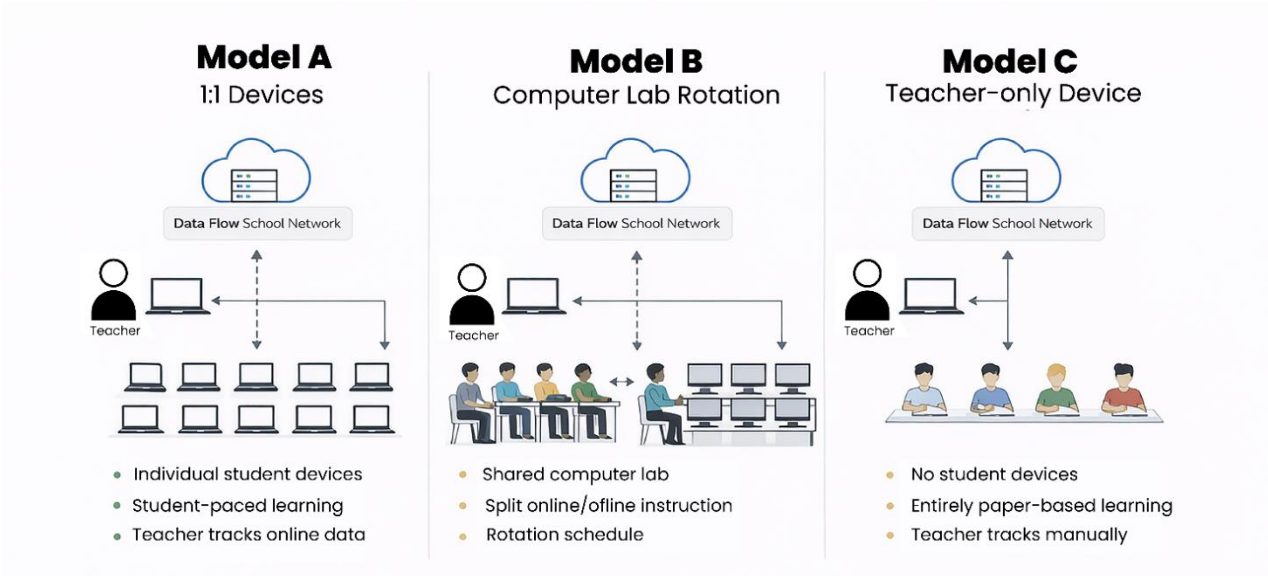

Figure 3. Three Classroom Implementation Models

4. 4 Community Engagement and Content Localization

To avoid past EdTech failures from lack of local ownership, the framework emphasizes community involvement through School Management Committee presentations, recruitment of volunteer tech champions, quarterly student portfolio showcases, and optional parent access via teacher-mediated logins. Content localization ensures cultural responsiveness through mathematics problems referencing Ghanaian market scenarios with local crops and currency, science examples using familiar flora and farming practices, gender-balanced illustrations, urban-rural scenario diversity, and disability accommodations including text-to-speech and adjustable fonts.

5. Challenges, Costs, and Ethics

5. 1 Challenges and Mitigations

Table 1 Structure and Learning Objectives of the Core and Auxiliary Cases

Challenge	Impact	Mitigation	Status
Device fragmentation	Compatibility	PWA (Android 6. 0+, 2 GB RAM)	Implemented
Power instability	Downtime	Solar ($180), 2-week caching	Design complete
Limited Twi data	72% accuracy	UG expansion (2,000 items)	In progress
Teacher literacy	Adoption risk	5-day training, peer networks	Piloted
Small Classes	BKT estimation	Prior smoothing	Implemented

5. 2 Economic Sustainability

The economic viability of this framework rests on realistic cost modeling that distinguishes between capital expenditure (one-time setup) and operating expenditure (recurring annual costs). Capital expenditure per school includes a Raspberry Pi 4 with accessories ($75), optional solar panel and battery for off-grid schools ($180), WiFi router ($25), and 64GB microSD card ($12). The largest variable involves student devices: if relying on bring-your-own-device policies, total CAPEX is $292 per school; if providing 40 tablets at $60 each, total CAPEX reaches $2,692 per school. Operating expenditure remains remarkably low: content updates and cloud hosting ($50/school = $0. 25/student), edge node maintenance ($30/school = $0. 15/student), and teacher training amortized over three years ($120/school = $0. 60/student) total just $1. 03 per student per year) - less than 1% of Ghana's per-pupil education expenditure. Return on investment projections based on our conservative 0. 45-0. 55

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standard deviation learning gains align with World Bank analysis estimating that 0. 5 improvement in mathematics achievement would increase Ghana's GDP by 1. 8% over 25 years [25], generating returns far exceeding initial investment costs.

Table 2. Comparative Analysis

Solution	Annual Cost/ student	Connectivity	Language Support	Offline	Effect Size
Khan Academy	$0 + $15/month	High bandwidth	English	No	d=0. 76 [2]
Microsoft Education	$12 + internet	Medium bandwidth	Limited	Limited	d=0. 52
Traditional Tutoring	$150-300	None	All	Yes	d=2. 0 [1]
Proposed Edge-AI	$1. 03	None	Twi/Ewe/ Ga/En	Yes	d=0. 45-0. 55

The economic sustainability of this framework is grounded in realistic cost modeling informed by Ghanaian infrastructure constraints. Capital expenditure per school ranges from $2,400 for a full one-to-one deployment (30 tablets, a $75 Raspberry Pi edge node, and $180 solar power for off-grid institutions) to just $292 under a Bring Your Own Device (BYOD) model, leveraging Ghana's 74. 6% mobile penetration rate [7]. Operational costs are projected at a minimal $1. 03 per student annually-less than 1% of the country's current per-pupil expenditure [25] covering ongoing maintenance, content updates, and teacher support. Crucially, the anticipated learning gain of 0. 45 standard deviations corresponds to a 1. 8% increase in long-term GDP [25], positioning this intervention as both an educationally transformative and economically sound investment aligned with SDGs 4 and 8

5. 3 Privacy and Ethics

The framework prioritizes data privacy and ethical AI deployment through multiple safeguards. Student data storage follows an edge-first architecture where personally identifiable information remains on local school servers, with only anonymized aggregates transmitted to cloud infrastructure when connectivity permits. This approach complies with Ghana's Data Protection Act 843 (2012), which requires explicit consent for data processing and mandates protection of minors' personal information. All system interactions with students and parents include consent mechanisms presented in accessible local languages (Twi, Ewe, Ga, English), ensuring informed participation across linguistic communities.

To address algorithmic bias and ensure equitable outcomes, the framework implements regular bias audits examining performance across gender, geographic location (urban/rural), and socioeconomic indicators. These audits follow UNESCO's AI Ethics Recommendation framework [26], which emphasizes transparency, accountability, human oversight, and inclusion. The teacher dashboard explicitly positions AI as advisory rather than deterministic, maintaining human decision-making authority and enabling teachers to override algorithmic recommendations based on contextual knowledge of individual students. Additionally, the system includes provisions for students and parents to request explanations of AI-generated recommendations, supporting transparency and building trust in technology-mediated learning environments.

6. Policy Recommendations and Strategic Alignment

6. 1 Alignment with Ghana's National Priorities

Ghana's National EdTech Strategy identifies three pillars- Digital Infrastructure, Teacher Capacity, and AI Preparedness [4] - and our framework advances all three simultaneously by making connectivity optional, embedding AI literacy into professional development, and offering a model exportable across Africa. The framework also maps directly onto SDG 4 targets, supporting universal

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quality education (4. 1), reducing gender and rural-urban disparities (4. 5), reinforcing literacy and numeracy goals (4. 6), and amplifying teacher effectiveness in under-resourced settings (4. c).

6. 2 Policy Recommendations for Ministry of Education

Five recommendations emerge for the Ministry of Education. First, procurement reform should require vendors to demonstrate offline-first functionality, minimum 40 hours of teacher training, support for at least three Ghanaian languages, three-year maintenance contracts, and compatibility with existing infrastructure. Second, edge infrastructure investment should allocate 2026-2030 EdTech budgets toward school-level edge servers, solar power for off-grid schools, and classroom Wi-Fi, estimated at $4. 5M over five years for all 15,000 schools, just 0. 1% of the education budget. Third, teacher AI literacy should be mandated in all Colleges of Education by 2027, with practicing teachers completing 20-hour adaptive learning professional development by 2028 and a compensated "AI Facilitator" career track established. Fourth, a multilingual EdTech mandate should require P1-P3 systems to support Twi, Ewe, and Ga, backed by a National Language Technology Fund and NLP research grants. Fifth, a data sovereignty framework should mandate Ghana-hosted data storage, establish a GES compliance office, and explicitly prohibit third-party sale of student data.

6. 3 Recommendations for International Partners

International partners should prioritize substance over visibility. Multilateral organizations like the World Bank and UNESCO should shift success metrics from connectivity rates to learning outcomes and pool funding across West African nations to build shared NLP corpora for Twi, Yoruba, and Hausa. Bilateral partners from China, the US, and UK should facilitate Edge AI academic exchanges, co-fund rigorous RCT evaluations, and require aid-funded EdTech to release code under Creative Commons. NGOs and foundations should replace one-off device donations with multi-year implementation partnerships covering hardware, training, maintenance, and evaluation, while investing in community ownership strategies that outlast donor engagement.

7. Conclusion and Future Directions

7. 1 Summary of Contributions

This paper has presented a framework for educational transformation through three integrated innovations: a hybrid edge-cloud architecture enabling offline-first adaptive learning via Bayesian Knowledge Tracing on 55-USD Raspberry Pi nodes, informed by deployments such as ASU's SolarSPELL; multilingual AI tutoring in Twi, Ewe, and Ga via AfriBERT a-LAFT, currently achieving 72% semantic fidelity with a target of 85%; and digital learning portfolios that support continuous, competency-based assessment aligned with Ghana's Standards-Based Curriculum. Together, these yield a replicable architecture aligned with Ghana's 2026 National EdTech Strategy, a practical African-language ITS framework operable under connectivity constraints ,an affordability model of approximately 1. 03 USD per student per year, and a policy roadmap explicitly grounded in SDG 4 (Quality Education) and SDG 9 (Industry, Innovation and Infrastructure).

7. 2 Limitations and Future Research

The current results are based on early-stage prototyping with a small sample (n = 5 teachers, n = 200 students), and should be interpreted as feasibility evidence rather than definitive impact estimates. Twi NLP performance remains at 72% accuracy, constraining the sophistication of language-based feedback; edge hardware cannot replicate cloud GPU capabilities for large-scale simulations or very deep models; and cost projections assume relatively stable hardware prices and reliable community maintenance. Future research should explore agentic AI approaches to dynamically generate and adapt educational content in African languages directly on edge devices [27], potentially reducing manual translation costs while enabling rapid content localization. Future research will include a Phase 2 randomized controlled trial to estimate causal learning effects, explore reinforcement learning for curriculum sequencing, and investigate affect-aware adaptations for engagement detection. Additional priorities include expanding coverage to secondary-level science subjects and conducting cross-national replications in contexts such as Nigeria, Cameroon, and Côte d'Ivoire to test transferability across francophone and anglophone systems.

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7. 3 Call to Action

Ghana's 2026 EdTech Strategy, the One Million Coders Programme and expanding international partnerships represent a rare convergence of policy, investment, and opportunity; yet without architectures explicitly designed for Ghanaian infrastructural and linguistic realities, this momentum risks repeating earlier cycles of unsustained EdTech pilots. Policymakers should initiate dedicated edge-AI pilots in 2026-2027 and revise procurement standards to prioritize offline capability, multilingual support, and teacher-centered analytics rather than raw device counts. Development partners should shift from one-off device donations toward multi-year system strengthening, measuring success by improvements in learning outcomes and equity rather than connectivity statistics alone. The technical architecture now exists, the policy momentum exists, and the human capacity exists; what remains is the collective commitment to build education systems that work for every Ghanaian child, with or without internet access.

References

[1] B.S.Bloom, Educational Researcher, vol.13, no.6, pp.4-16, 1984.

[2] K. VanLehn, Educational Psychologist, vol. 46, no. 4, pp. 197-221, 2011.

[3] UNESCO Institute for Statistics, "Education in Sub-Saharan Africa: Regional Report on SDG 4," Montreal: UNESCO-UIS, 2023, p. 15.

[4] Ferdinand Ellis,"Deputy Minister Launches 3rd EdTech Stakeholder Forum, Reaffirms Government's Digital Transformation Agenda in Education," EducationGhana, Sept. 22, 2025. Available: https://educationghana. org/deputy-minister-launches-3rd-edtech-stakeholder-forum-reaffirms-governments-digital-transformation-agenda-in-education/

[5] Ghana High Commission Pretoria, "President Mahama Launches One Million Coders Programme" July 29, 2025. [Online]. Available: https://pretoria. mfa. gov. gh/president-mahama-launches-one-million-coders-programme/

[6] Ghana Education Service, Annual Report 2022, 2023.

[7] DataReportal, Digital 2026: Ghana. [Online]. Available: https://datareportal. com/reports/digital-2026-ghana

[8] B. S. Bloom, "Learning for Mastery," Evaluation Comment, vol. 1, no. 2, pp. 1-12, 1968.

[9] A. Ghosh, J. Raspat, and S. Heffernan, in Handbook of AI in Education, C. Holmes and K. Porayska-Pomsta, Eds. Cheltenham: Edward Elgar, 2023, pp. 98-140.

[10] J.R.Anderson, C. F. Boyle, and B. J. Reiser, Science, vol. 228, no. 4698, pp. 456-462, 1985.

[11] A.T.Corbett and J.R.Anderson, User Modeling and User-Adapted Interaction, vol.4, no 4, pp. 253-278, 1995.

[12] C.Piech et al., in Proc. NIPS, 2015, pp. 505-513.

[13] B.D.Nye, Int.J.Artif. Intell. Educ, vol.25, no.2, pp.177-203, 2015.

[14] M. Warschauer, Technology and Social Inclusion. Cambridge, MA: MIT Press, 2003.

[15] E.A.Onyame, F.Sam, A.-G.Sayibu, V.F.Addison, and D.G.Essel, “Assessing the easibility of Implementing a Learning Management System (LMS)in Senior High Schools (SHS) in the Cape Coast Metropolis: Infrastructure,Readiness, and Challenges,” Journal of Information and Technology,vol. 5, no.11, pp.1-23, Oct.2025.

[16] J. Cummins, Rev. Educ. Res, vol. 49, no. 2, pp. 222-251, 1979.

[17] A. R. Van Barneveld, L. E. Arnold, and J. P. Campbell, EDUCAUSE Rev, vol. 47, no. 4, pp.44-56, 2012.

https://doi.org/10.58244/joerai.263721

[18] M.A.Klenowski, Assessment Matters,vol.1, pp.7-28, 2009.

[19] B.Jacob et al, in Proc.CVPR, 2018, pp.2704-2713.

[20] ASU SolarSPELL, 2025 Impact Report, 2026.

[21] B.F.P.Dossou, J.S.Pedro, and C.Emezue, "AfroLM: A Self-Active Learning-based Multilingual Pretrained Language Model for 23 African Languages," in Proc. SustaiNLP Workshop at EMNLP, Dec.2022, pp.52-64.

[22] D.M.Marilign and E.N.Alemu, in Proc. Widening NLP, 2025, pp. 130-138.

[23] Z.Chen, et al, "Efficient Deployment of Peanut Leaf Disease Detection Models on Edge AI Devices," Agriculture, vol.15, no.3, p.332, Feb.2025.doi: 10.3390/agriculture15030332.

[24] M. Shapiro et al, in Proc.SSS, 2011, pp.386-400.

[25] World Bank, Ghana Education Analysis 2023,2023.

[26] UNESCO, AI Ethics Recommendation,2021.

[27] R. Gupta and G. Bhatia, "Agentic Educational Content Generation for African Languages on Edge Devices," arXiv preprint arXiv:2511. 07437, Nov. 2025.