Technology Integration and Educational Equity: Assessing Digital Resource Gaps in Junior Secondary Schools Under Kenya's Competency-Based Curriculum

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ABSTRACT

Background: Kenya's transition to a Competency-Based Curriculum (CBC) in 2017 necessitated unprecedented integration of digital technologies, with junior secondary schools (Grades 7-9) facing acute challenges in bridging digital resource gaps. Whilst the CBC framework emphasises learner-centred, technology-enhanced pedagogy to develop 21st-century competencies, significant disparities in digital infrastructure, connectivity, and device availability threaten to exacerbate educational inequities across diverse school contexts.

Objective: This study assessed digital resource gaps in junior secondary schools implementing Kenya's CBC, examining disparities in technological infrastructure, teacher competencies, learner access to devices, and the relationship between digital resource availability and curriculum implementation fidelity.

Methods: A mixed-methods convergent parallel design surveyed 847 teachers and 156 administrators from 312 junior secondary schools across 15 counties, complemented by qualitative interviews with 45 stakeholders and observational assessments in 60 schools. Quantitative data were analysed using descriptive statistics, chi-square tests, and multiple regression, whilst qualitative data underwent thematic analysis.

Results: Significant digital divides emerged: only 23% of public schools versus 78% of private institutions had functional computer laboratories; learner-to-device ratios averaged 47:1 in rural schools versus 8:1 in urban private schools; internet connectivity was available in 31% of schools, averaging 2.3 Mbps where present. Teacher digital literacy correlated significantly with implementation quality ($r=0.67$, $p<0.001$). Multiple regression analysis revealed that teacher competencies ($\beta=0.42$, $p<0.001$) and infrastructure availability ($\beta=0.31$, $p<0.001$) significantly predicted CBC implementation fidelity ($R^2=0.59$, $F=87.34$, $p<0.001$), with interaction effects suggesting multiplicative rather than additive disadvantage for rural public schools.

Conclusions: Substantial digital resource gaps persist, systematically disadvantaging learners in rural, public, and low-income contexts. These findings extend van Dijk's multi-dimensional digital divide framework by demonstrating cascading inequities wherein infrastructure gaps compound through skills deficits into divergent learning outcomes, with sustainability failures creating cyclical disadvantage patterns. Addressing these requires coordinated policy interventions, targeted infrastructure investment, comprehensive teacher capacity building, and sustainable support systems to prevent technology from becoming a new dimension of educational inequality.

Keywords: Competency-Based Curriculum; digital divide; educational equity; technology integration; junior secondary education; digital infrastructure; Kenya education policy

INTRODUCTION

The digital revolution has fundamentally transformed educational paradigms globally, positioning technology integration not merely as an enhancement but as an essential component of contemporary pedagogy (UNESCO,

2023). As nations worldwide pursue education systems that prepare learners for increasingly digitized economies and societies, the intersection of technology adoption and educational equity has emerged as a critical policy concern, particularly in developing contexts where resource constraints compound implementation challenges (World Bank, 2021). Kenya's ambitious educational reform through the Competency-Based Curriculum represents a bold commitment to this transformation, yet the promise of technology-enhanced learning risks remaining unfulfilled for millions of learners if fundamental digital resource gaps remain unaddressed.

The integration of digital technologies in education has evolved through distinct phases since the 1980s. Initial efforts focused on computer literacy and basic ICT skills, progressing through multimedia learning environments in the 1990s, internet-enabled collaborative learning in the 2000s, and currently emphasizing mobile learning, artificial intelligence, and personalized adaptive systems (Selwyn, 2016). The COVID-19 pandemic accelerated this trajectory dramatically, exposing both the potential and limitations of digital learning while highlighting stark inequities in technological access (OECD, 2021). Sustainable Development Goal 4, which commits nations to "ensure inclusive and equitable quality education," explicitly recognizes technology's role in expanding educational opportunities while cautioning against digital divides that perpetuate disadvantage (United Nations, 2015).

Across sub-Saharan Africa, technology integration in education has been characterized by ambitious policy frameworks often outpacing implementation capacity (Trucano, 2020). Countries like Rwanda, Ghana, and South Africa have invested substantially in educational technology infrastructure, with varying degrees of success shaped by infrastructure challenges, teacher preparedness, and sustainability concerns (Isaacs, 2012). The African Union's Digital Transformation Strategy for Africa (2020-2030) prioritizes educational digitalization as essential for continental development, yet persistent challenges including unreliable electricity, limited internet connectivity, and insufficient device availability constrain progress across the region (African Union, 2020).

Kenya has demonstrated continental leadership in digital innovation, earning recognition as a technology hub through initiatives like M-Pesa mobile banking and a thriving startup ecosystem (Ndemo & Weiss, 2017). In education specifically, the government's Digital Literacy Programme (2016) represented one of Africa's most ambitious educational technology initiatives, distributing over 1.2 million tablets to primary schools (Ministry of Education, 2016). However, implementation faced significant challenges including device maintenance, content inadequacy, teacher unpreparedness, and infrastructure limitations that ultimately compromised program effectiveness (Wanzala, 2019). The subsequent launch of the Competency-Based Curriculum in 2017, with its heavy emphasis on technology-mediated learning, raised urgent questions about the system's capacity to deliver equitable digital education experiences across Kenya's diverse school contexts.

Problem Statement

Despite Kenya's policy commitment to technology-enhanced competency-based education, substantial evidence suggests that digital resource availability varies dramatically across junior secondary schools, creating a new dimension of educational inequality that threatens to undermine curriculum reform objectives. While affluent urban schools increasingly resemble their counterparts in developed nations—equipped with computer laboratories, interactive whiteboards, high-speed internet, and one-to-one device programs—many rural and marginalized urban schools lack even basic digital infrastructure (Mwania & Muola, 2020). This digital divide manifests not only in hardware and connectivity but extends to teacher digital competencies, technical support availability, appropriate digital content, and institutional capacity for sustainable technology integration (Mwangi & Njagi, 2021).

The implications extend beyond simple access inequity. The CBC framework explicitly embeds digital literacy and technology utilization across learning areas, making digital competence both a learning objective and a pedagogical medium (Kenya Institute of Curriculum Development, 2017). Learners without adequate digital exposure risk falling behind not only in ICT-specific competencies but across the curriculum, where technology increasingly mediates content delivery, assessment, and skill development. This situation potentially creates a two-tier system where educational outcomes increasingly correlate with technological privilege rather than

learner ability or effort, contradicting fundamental equity principles underlying universal education provision (Wangari & Okoth, 2022).

This study therefore aimed to assess digital resource gaps across junior secondary schools implementing Kenya's CBC, examining how these disparities affect curriculum implementation fidelity and learner outcomes. Specific objectives included: (1) To determine the current status of digital infrastructure (devices, connectivity, facilities) across diverse junior secondary school contexts, (2) To assess teacher digital competencies and their relationship to effective CBC implementation, (3) To identify systemic factors contributing to digital resource disparities between schools, (4) To examine stakeholder perspectives on technology integration challenges and opportunities and (5) To propose evidence-based recommendations for bridging digital divides and ensuring equitable educational outcomes.

The research addressed four primary questions: (1) What is the extent of digital resource availability across junior secondary schools implementing CBC in Kenya? (2) How do digital resource gaps differ across school types, locations, and socioeconomic contexts? (3) What relationship exists between digital resource availability and curriculum implementation quality? And (4) What policy and practical interventions can effectively address identified digital equity gaps?

Conceptual Framework

This study was guided by an integrated conceptual framework synthesizing three complementary theoretical perspectives: the Digital Divide Framework (van Dijk, 2020), the Technology Acceptance Model (Davis, 1989; Venkatesh & Bala, 2008), and Vygotsky's Sociocultural Theory of Learning (1978) as applied to technology-mediated education.

Van Dijk's (2020) refined Digital Divide Framework recognizes multiple dimensions of technological inequality extending beyond simple access to include skills, usage patterns, and tangible outcomes. This framework distinguishes between motivational access (psychological attitudes toward technology), material access (physical infrastructure and devices), skills access (digital literacy and competencies), and usage access (meaningful application opportunities). Applied to educational contexts, this multidimensional perspective reveals how digital inequity compounds across layers, with initial infrastructure gaps cascading into skills deficits and ultimately divergent learning outcomes (Resta & Laferrière, 2015).

The Technology Acceptance Model provides insight into factors influencing technology adoption and effective utilization by educators and learners. This model posits that perceived usefulness and perceived ease of use significantly determine technology acceptance, mediated by factors including system quality, institutional support, and user characteristics (Holden & Rada, 2011). In educational settings, teacher technology acceptance critically influences implementation fidelity, suggesting that infrastructure provision alone proves insufficient without addressing attitudinal and capability dimensions.

Vygotsky's Sociocultural Theory emphasizes learning as fundamentally social and culturally mediated, with tools—including digital technologies—serving as cultural mediators that shape cognitive development (Kozulin, 2003). This perspective positions educational technology not as neutral instructional delivery mechanisms but as cultural tools that can either bridge or widen learning opportunity gaps depending on how they are deployed and supported. The Zone of Proximal Development concept particularly illuminates how appropriate technological scaffolding, guided by digitally competent teachers, can accelerate learner development, while inadequate support structures may leave learners unable to progress (Warschauer & Matuchniak, 2010).

Integrating these theoretical lenses, this study conceptualizes digital resource gaps as multidimensional phenomena encompassing infrastructure, competencies, support systems, and outcomes. The framework recognizes that addressing educational technology equity requires coordinated interventions across material, human capacity, and institutional dimensions, guided by evidence regarding how these elements interact to enable or constrain effective CBC implementation.

LITERATURE REVIEW

Analytical Framework: Extending the Multi-Dimensional Digital Divide Model

Whilst existing literature extensively documents digital inequities in education, this study advances theoretical understanding by applying and extending van Dijk's (2020) multi-dimensional digital divide framework specifically to competency-based curriculum implementation in developing contexts. We propose a cascade model wherein digital resource gaps compound across four interconnected dimensions—infrastructure access, skills development, pedagogical integration, and learning outcomes—with each deficit amplifying subsequent disparities.

This framework differs from prior research in three ways. First, it moves beyond binary access/no-access conceptualisations to examine quality gradients within resource categories (functional versus non-functional devices; adequate versus inadequate bandwidth). Second, it incorporates interaction effects, recognising that disadvantages multiply rather than accumulate additively, particularly affecting rural public schools. Third, it foregrounds sustainability as a distinct dimension, demonstrating how unsustained technology investments create cyclical rather than linear disadvantage patterns.

The Technology Acceptance Model (Davis, 1989; Venkatesh & Bala, 2008) provides complementary insight into adoption mechanisms, positing that perceived usefulness and perceived ease of use significantly determine technology acceptance, mediated by system quality, institutional support, and user characteristics (Holden & Rada, 2011). In educational settings, teacher technology acceptance critically influences implementation fidelity, suggesting that infrastructure provision alone proves insufficient without addressing attitudinal and capability dimensions.

Vygotsky's sociocultural theory (1978) positions technology as cultural mediator that either bridges or widens learning opportunity gaps depending on deployment and support. The Zone of Proximal Development concept particularly illuminates how appropriate technological scaffolding, guided by digitally competent teachers, can accelerate learner development, whilst inadequate support structures may leave learners unable to progress (Warschauer & Matuchniak, 2010).

Integrating these theoretical lenses, we conceptualise digital equity as requiring simultaneous intervention across material, human capacity, and institutional dimensions—a proposition empirically tested through this study's multi-level data collection.

Educational Technology and Equity: Critical Perspectives

Educational technology's paradoxical potential to both democratise and stratify learning access remains unresolved in scholarship (Warschauer & Matuchniak, 2010). Optimistic perspectives emphasise technology's capacity to transcend geographical barriers, personalise learning, and develop digital age competencies (UNESCO, 2023), with the COVID-19 pandemic demonstrating technology's critical role in maintaining educational continuity (OECD, 2021).

However, critical scholarship increasingly documents how technology integration absent equity considerations often reproduces and amplifies existing stratification (Livingstone & Helsper, 2007). The "digital divide" concept has evolved from simple binary distinctions to recognise multiple interconnected divides in access quality, usage patterns, skills development, and outcomes (van Dijk, 2020). Robinson et al. (2020) demonstrate that even when basic access barriers are overcome, substantial disparities persist in technology utilisation, with advantaged populations leveraging digital resources for capital-enhancing activities whilst disadvantaged groups predominantly engage in entertainment-focused consumption.

Particularly relevant to this study, Vigdor et al. (2014) found that home computer access negatively impacted academic achievement among lower-income students, suggesting that access without appropriate guidance may prove counterproductive. This challenges infrastructure-centric policy approaches common in developing

contexts, indicating that equitable technology integration requires complementary investments in capacity building and support systems.

Technology Integration in African Education: Implementation Lessons

Sub-Saharan Africa's educational technology landscape reflects unique challenges shaped by infrastructure deficits, resource constraints, and compressed technological evolution (Trucano, 2020). Unlike developed regions where educational technology evolved gradually, many African nations must simultaneously address fundamental infrastructure gaps whilst adopting cutting-edge approaches—creating both leapfrogging opportunities and implementation risks (Isaacs, 2012).

Rwanda's One Laptop Per Child initiative offers instructive lessons: whilst successfully distributing devices to over 300,000 learners, evaluations revealed minimal learning impact attributable to inadequate teacher training, insufficient technical support, limited appropriate content, and failure to integrate device use meaningfully into pedagogy (Cristia et al., 2017; Toyama, 2015). Similarly, Ghana's Better Ghana Laptop Project demonstrated gaps between policy ambition and implementation reality, with device distribution delays, inadequate teacher preparation, and limited content localisation undermining effectiveness (Mereku et al., 2015). South Africa's extensive interactive whiteboard investment revealed expensive infrastructure underutilisation stemming from teacher discomfort, insufficient training, and technical maintenance challenges (Hennessy et al., 2010).

These continental experiences collectively emphasise that hardware provision alone cannot drive educational transformation—sustainable technology integration requires ecosystem development addressing procurement, maintenance, technical support, content development, and teacher capacity simultaneously.

Kenya's CBC and Technology Integration: Context and Challenges

Kenya's Competency-Based Curriculum, launched in 2017, represents fundamental pedagogical reconceptualisation emphasising learner-centred, competency-focused education with substantial technology integration requirements (KICD, 2017). The curriculum explicitly embeds digital literacy across learning areas, making technology both learning objective and pedagogical medium. This approach aligns with international trends recognising digital competence as essential 21st-century skill whilst leveraging technology to enable competency-based pedagogical approaches (UNESCO, 2018).

However, implementation occurs against the backdrop of Kenya's earlier Digital Literacy Programme challenges. Launched in 2016, the DLP distributed over 1.2 million tablets to primary schools, representing one of Africa's most ambitious educational technology initiatives (Ministry of Education, 2016). Implementation faced significant challenges including device maintenance, content inadequacy, teacher unpreparedness, and infrastructure limitations that ultimately compromised programme effectiveness (Wanzala, 2019; Kihara, 2018).

Emerging research indicates highly variable CBC implementation, with substantial disparities between well-resourced and under-resourced schools (Mwangi & Njagi, 2021). Teachers in infrastructure-poor contexts report reverting to traditional methods despite curriculum expectations, creating systematic disparities wherein advantaged learners receive intended competency-based, technology-rich education whilst disadvantaged peers experience diluted versions emphasising rote learning (Njagi & Mwania, 2021).

Teacher Capacity as Critical Mediating Factor

International research consistently identifies teacher capacity as the most critical factor determining educational technology effectiveness (Hatlevik et al., 2018). Ertmer and Ottenbreit-Leftwich (2010) distinguish between first-order barriers (infrastructure, access) and second-order barriers (beliefs, knowledge, culture), arguing that whilst first-order barriers receive disproportionate policy attention, second-order barriers more fundamentally constrain meaningful technology integration.

Teacher technology acceptance and integration are shaped by multiple factors including perceived usefulness, ease of use, institutional support, prior experience, and pedagogical beliefs (Tondeur et al., 2017). Teachers viewing technology primarily as administrative burden rather than pedagogical asset demonstrate minimal

integration regardless of infrastructure availability (Ertmer et al., 2012). Conversely, teachers recognising technology's potential for enhancing engagement and personalising learning actively seek integration opportunities even with limited infrastructure (Howard & Gigliotti, 2016).

Professional development quality critically influences teacher technology integration capacity. Traditional cascade training models, common in developing contexts including Kenya's DLP, prove largely ineffective due to superficial skill development, insufficient practice opportunities, and lack of sustained follow-up support (Trust et al., 2016). Effective professional development requires extended duration, active learning experiences, content focus, coherence with curriculum, collective participation, and embedded ongoing support (Desimone & Garet, 2015)—characteristics largely absent in current Kenyan teacher development systems.

Research Gaps and Study Contribution

Whilst substantial literature addresses educational technology in developed contexts and emerging research examines African implementations, significant gaps remain regarding Kenya's specific CBC context. Most existing Kenyan studies focus on primary education or examine secondary schooling generally without addressing junior secondary's unique transitional positioning (Mwania & Muola, 2020). The CBC's technology integration requirements differ substantially from predecessor curricula, yet limited research empirically documents implementation realities under this new framework.

Furthermore, existing literature often emphasises either infrastructure availability or teacher competencies in isolation, rarely examining how multiple digital divide dimensions interact to shape implementation outcomes (Wangari & Okoth, 2022). The relationship between digital resource availability and actual curriculum implementation fidelity remains underexplored, with most studies assuming rather than demonstrating that infrastructure gaps constrain pedagogical practice.

This study makes four distinct contributions to address these gaps:

First, it extends van Dijk's multi-dimensional digital divide framework by empirically demonstrating cascading inequities wherein infrastructure gaps compound through skills deficits into divergent learning outcomes, with sustainability failures creating cyclical disadvantage patterns not previously documented in competency-based curriculum contexts.

Second, it provides empirical evidence of interaction effects—showing that rural public schools experience multiplicative rather than additive disadvantage, with compound effects exceeding what simple summation of location and school-type effects would predict.

Third, it demonstrates through regression analysis that teacher competencies mediate the infrastructure-outcomes relationship, indicating that whilst infrastructure provision is necessary, teacher capacity proves more critical to implementation quality—a finding with direct policy implications for resource allocation priorities.

Fourth, it documents the emergence of a two-tier CBC implementation system wherein systematic bifurcation creates parallel educational realities determined by technological privilege rather than learner ability, contradicting fundamental equity principles underlying universal education provision.

METHODOLOGY

Research Design

This study employed a mixed-methods convergent parallel design, simultaneously collecting and analyzing quantitative and qualitative data before integrating findings to provide comprehensive understanding of digital resource gaps in junior secondary schools (Creswell & Plano Clark, 2018). This approach recognized that quantitative methods could establish the extent and patterns of digital divides across the education system, while qualitative methods illuminated the contextual factors, stakeholder experiences, and implementation dynamics that statistics alone cannot capture (Tashakkori & Teddlie, 2010). The convergent design allowed triangulation

of findings from multiple data sources, enhancing validity and providing nuanced insights into both the "what" and "why" of technology integration challenges.

The target population comprised all junior secondary schools (Grades 7-9) implementing CBC in Kenya, estimated at approximately 10,847 schools as of the 2023 academic year (Ministry of Education, 2023). Given resource constraints precluding full population enumeration, a stratified random sampling approach ensured representation across key dimensions likely to influence digital resource availability: school type (public/private), location (urban/rural), and county (provincial region).

Quantitative Sample: Using Yamane's (1967) formula with 95% confidence level and 5% margin of error, a minimum sample of 385 schools was determined. To ensure adequate representation across strata and account for potential non-response, the target sample was expanded to 400 schools. Through probability proportional to size sampling within each stratum, 312 schools ultimately participated (78% response rate), representing 15 of Kenya's 47 counties. County selection employed stratified random sampling ensuring representation across former provincial boundaries and varied development levels based on county human development indices.

Within participating schools, all teachers handling junior secondary classes were invited to complete surveys, yielding 847 teacher respondents. School administrators (principals/head teachers) served as institutional informants, with 156 participating (one per school for single-stream institutions, multiple for larger schools). This approach provided both individual-level data regarding teacher competencies and experiences and institutional-level data regarding infrastructure and policies.

Qualitative Sample: Purposive sampling identified 60 schools for in-depth qualitative investigation, deliberately selecting cases representing the full spectrum of digital resource availability and contextual diversity. This included 20 well-resourced schools (primarily urban private institutions), 20 moderately resourced schools (urban public and semi-urban private), and 20 under-resourced schools (primarily rural public). Within these 60 schools, 45 stakeholders participated in semi-structured interviews: 25 teachers, 10 school administrators, and 10 curriculum support officers. Selection criteria emphasized information richness, seeking participants with substantial CBC implementation experience and willingness to reflect critically on technology integration challenges.

Data Collection Instruments

School Infrastructure Survey: A comprehensive 87-item instrument adapted from UNESCO's ICT in Education Monitoring and Evaluation Framework (2023) assessed digital infrastructure across multiple dimensions: physical facilities (computer laboratories, internet connectivity, electricity reliability), device availability (computers, tablets, projectors, interactive boards), technical specifications (device functionality, internet bandwidth, network security), maintenance systems, and technology acquisition histories. Institutional informants (administrators) completed this survey, providing systematic comparable data across schools.

Teacher Digital Competency and Integration Survey: A 76-item instrument combined adapted scales from the Teacher ICT Competency Framework (UNESCO, 2018) and the Technology Acceptance Model questionnaire (Venkatesh & Bala, 2008). Sections assessed: demographic characteristics, digital literacy self-efficacy using Likert scales (1=no competency to 5=expert competency) across basic operations, content creation, digital pedagogy, and assessment; technology integration frequency and pedagogical approaches; perceived barriers to integration; professional development experiences; and attitudes toward technology in education. Reliability testing during piloting yielded Cronbach's alpha coefficients ranging from 0.83 to 0.91 across subscales, indicating strong internal consistency.

CBC Implementation Fidelity Checklist: A 54-item observational instrument operationalized CBC implementation quality across key dimensions: learner-centered pedagogy, competency-based assessment practices, technology integration in content delivery, and digital literacy development. Trained research assistants conducted classroom observations using this structured checklist, rating each dimension on 5-point scales. Implementation scores provided dependent variables for examining relationships between digital resource availability and curriculum enactment quality.

Semi-Structured Interview Protocols: Three distinct protocols addressed teacher experiences, administrator perspectives, and curriculum support officer observations. Teacher interviews (45-60 minutes) explored technology integration experiences, perceived barriers and enablers, training adequacy, learner digital literacy levels, and CBC implementation challenges. Administrator interviews (60-75 minutes) examined institutional technology strategies, resource allocation decisions, policy implementation, community engagement, and sustainability concerns. Curriculum support officer interviews (60 minutes) provided systemic perspectives on implementation patterns, county-level variations, and policy-practice gaps.

Data Collection Procedures

Data collection occurred over four months (January-April 2024) through trained research assistants supervised by the principal investigator. Quantitative surveys were administered both electronically (using SurveyMonkey for accessible schools) and in paper format (for schools with limited connectivity), with research assistants available to clarify questions and ensure completion quality. Response rates were enhanced through multiple follow-up contacts and modest participation incentives (airtime vouchers).

Qualitative interviews were conducted face-to-face in participants' preferred languages (English or Kiswahili), audio-recorded with consent, and subsequently transcribed. Observational assessments involved full-day school visits, including multiple classroom observations, infrastructure inspections, and informal conversations with learners and staff. Field notes captured contextual details and researcher reflections augmenting formal instruments.

Data Analysis

Quantitative Analysis: Data were analyzed using SPSS Version 28. Descriptive statistics (frequencies, percentages, means, standard deviations) characterized digital resource availability, teacher competencies, and implementation fidelity across the sample. Inferential statistics examined relationships and differences: chi-square tests assessed associations between categorical variables (school type, location) and infrastructure availability; independent samples t-tests and ANOVA compared mean digital resource levels across groups; Pearson correlation coefficients examined relationships between continuous variables (digital resources, teacher competencies, implementation fidelity); and multiple regression analysis modeled factors predicting CBC implementation quality. Statistical significance was set at $p<0.05$.

Qualitative Analysis: Thematic analysis following Braun and Clarke's (2006) framework identified patterns within interview transcripts and observational field notes. The analysis proceeded iteratively through: familiarization (reading and re-reading transcripts), initial coding (systematic identification of interesting features), theme development (organizing codes into potential themes), theme review (checking themes against data), theme definition and naming, and report writing. NVivo 14 software facilitated data management and coding processes. A reflexive approach acknowledged researcher positionality and potential biases, with peer debriefing and member checking enhancing trustworthiness.

Integration: Following convergent parallel conventions, quantitative and qualitative findings were analyzed independently before systematic integration during interpretation (Creswell & Plano Clark, 2018). Integration involved comparing datasets to identify convergence (mutual confirmation), divergence (contradictions requiring explanation), and complementarity (different aspects of phenomena illuminated). Joint displays visually presented integrated findings, facilitating identification of meta-inferences drawing on both data types.

Ethical Considerations

Ethical approval was obtained from the Kenya National Commission for Science, Technology and Innovation (NACOSTI) and relevant County Education Offices. Schools provided institutional consent, while individual participants gave informed consent after receiving detailed study information in accessible language. Participation was voluntary with no penalties for declining or withdrawing. Confidentiality was maintained through code assignment, with identifiable information accessible only to the research team. Data were stored

securely with restricted access. Findings reporting maintains participant and institutional anonymity through pseudonyms and aggregate reporting preventing individual identification.

RESULTS AND DISCUSSION

Analytical Overview: Predictors of CBC Implementation Fidelity

Multiple regression analysis modelling CBC implementation fidelity as the dependent variable revealed that digital resources significantly predicted implementation quality even when controlling for contextual factors. The full model (including infrastructure availability index, teacher digital competency scores, school type, location classification, and average class size) explained 59% of variance in implementation fidelity scores ($R^2=0.59$, $F=87.34$, $p<0.001$), indicating substantial predictive power.

Teacher digital competencies emerged as the strongest predictor ($\beta=0.42$, $p<0.001$), followed by infrastructure availability ($\beta=0.31$, $p<0.001$) and school type ($\beta=0.18$, $p<0.01$). Location and class size also contributed significantly but with smaller effect sizes ($\beta=0.12$ and $\beta=-0.09$ respectively, both $p<0.05$). These findings suggest that whilst infrastructure matters significantly, teacher capacity proves more critical to implementation quality—a pattern with important policy implications regarding resource allocation priorities.

Importantly, interaction effects were observed between infrastructure availability and teacher competencies ($\beta=0.15$, $p<0.01$), indicating that these factors work synergistically rather than independently. Teachers in well-resourced schools developed higher competencies through practice opportunities unavailable to colleagues in infrastructure-poor contexts, creating reinforcing cycles wherein initial advantages compound over time. This pattern supports our cascade model, demonstrating that addressing digital divides requires simultaneous intervention across infrastructure and human capacity rather than sequential approaches.

Effect sizes (Cohen's d) provided additional perspective on practical significance: the difference in implementation fidelity between high and low teacher competency groups yielded $d=1.23$, representing a large effect, whilst infrastructure differences yielded $d=0.87$, a medium-to-large effect. These substantial effect sizes indicate that observed differences have meaningful real-world implications for educational quality and learner outcomes.

Digital Infrastructure: Systematic Disparities Across School Contexts

Quantitative assessment revealed substantial digital resource disparities confirming significant inequities foundational to CBC implementation. Overall, only 34% of surveyed schools possessed functional computer laboratories meeting minimum standards (at least 20 working computers with appropriate furniture and security), whilst internet connectivity was available in 31% of schools, averaging merely 2.3 Mbps where connections existed—grossly inadequate for concurrent multi-user access required for classroom integration.

Chi-square tests confirmed that school type and location significantly predicted digital resource availability across all measured dimensions. For computer laboratory presence: $\chi^2(1, N=312)=167.34$, $p<0.001$, $\varphi=0.73$ (large effect); for internet connectivity: $\chi^2(1, N=312)=143.21$, $p<0.001$, $\varphi=0.68$ (large effect); for functional device availability: $\chi^2(1, N=312)=198.45$, $p<0.001$, $\varphi=0.80$ (large effect). These large effect sizes indicate that school type represents a fundamental determinant of digital resource access, not merely a statistical association.

Similarly, urban-rural location proved a powerful predictor. Urban schools significantly outperformed rural counterparts in computer laboratory availability ($\chi^2=89.23$, $p<0.001$, $\varphi=0.53$), internet access ($\chi^2=112.56$, $p<0.001$, $\varphi=0.60$), reliable electricity ($\chi^2=76.89$, $p<0.001$, $\varphi=0.50$), and device-to-learner ratios. Analysis of variance revealed significant location effects on device ratios: $F(3, 308)=234.56$, $p<0.001$, $\eta^2=0.70$, representing a large effect size.

Critically, rural public schools experienced compounded disadvantage exceeding additive effects of rural location and public status alone, supporting our interaction hypothesis. Mean device-to-learner ratios illustrated this pattern: urban private schools averaged 8:1, urban public 28:1, rural private 19:1, but rural public schools

47:1. Statistical interaction analysis confirmed significant location × school type interaction ($F=18.76$, $p<0.001$), indicating multiplicative rather than additive effects.

Qualitative observations illuminated these statistics' practical implications. In Mathare Secondary School (pseudonym), a rural public institution in Nyanza Province, observers noted a single non-functional desktop computer in locked storage, nominally constituting the school's "computer laboratory." The head teacher explained that learners had never interacted with computers. Conversely, at Premier Academy (pseudonym), an urban private school in Nairobi County, two fully equipped computer laboratories contained 40 recent-model computers, high-speed fibre internet, interactive whiteboards, and full-time ICT coordination. This stark contrast crystallised profoundly different CBC experiences based solely on school context.

Teacher Digital Competencies: Capacity Deficits and Mediation Effects

Teacher digital competency assessment revealed widespread deficits constraining technology integration even where infrastructure existed. Using UNESCO's (2018) ICT Competency Framework adapted five-point scales, only 18% of teachers self-rated as "proficient" (4) or "expert" (5) across basic operations, content creation, and digital pedagogy dimensions. Mean competency scores varied significantly by school context: rural public school teachers ($M=2.1$, $SD=0.8$) reported substantially lower competencies than urban private counterparts ($M=3.7$, $SD=0.6$), with this difference statistically significant and representing a large effect: $t(845)=18.34$, $p<0.001$, $d=2.24$.

Correlation analyses demonstrated strong relationships between teacher digital competencies and multiple outcome variables: technology integration frequency ($r=0.73$, $p<0.001$), CBC implementation fidelity scores ($r=0.67$, $p<0.001$), and perceived effectiveness of technology-enhanced lessons ($r=0.71$, $p<0.001$). These large correlations suggest that teacher capacity critically mediates between infrastructure availability and meaningful utilisation—infrastructure proves necessary but insufficient without capable users.

Professional development experiences demonstrated systematic inadequacy despite surface-level provision. Whilst 78% of teachers reported receiving some technology-related training, quality and depth proved problematic. Training duration averaged merely 2.3 days ($SD=1.4$), far below the sustained engagement research identifies as effective (Desimone & Garet, 2015 recommend minimum 20-40 hours). Content focused predominantly on basic computer operations (mentioned by 82% of trained teachers) rather than pedagogical integration (only 23% covered effective integration strategies). Delivery employed cascade models with progressive content dilution, whilst 91% received no post-training mentoring or coaching.

Teachers identified substantial unmet professional development needs: pedagogical integration strategies (mentioned by 87% of respondents), subject-specific technology applications (79%), managing technology in under-resourced contexts (71%), creating and adapting digital content (68%), assessing digital competencies (64%), and troubleshooting common technical issues (59%). These needs align with international best practices yet remain largely unaddressed in current Kenyan teacher development systems.

Implementation Fidelity: Systematic Bifurcation of Educational Experience

Classroom observations using structured CBC implementation fidelity checklists provided qualitative evidence of infrastructure-implementation relationships. In technology-rich schools (top quartile of infrastructure index), observers documented: frequent learner engagement with digital content (observed in 78% of lessons), teacher use of multimedia presentations enhancing concept visualisation (64% of lessons), online research activities developing information literacy (42% of lessons), collaborative digital projects building communication competencies (31% of lessons), and digital portfolio assessment providing authentic competency evidence (28% of schools). These practices closely aligned with CBC pedagogical intentions.

Conversely, in infrastructure-poor schools (bottom quartile), observers noted: predominant chalk-and-talk instruction despite curriculum expectations (91% of lessons), minimal learner technology interaction (technology used in only 8% of observed lessons), textbook-centric learning limiting content breadth (87% of lessons), teacher-centred pedagogy contradicting CBC learner-centredness (83% of lessons), and traditional

written examinations rather than competency-based assessment (94% of schools). Teachers in these contexts described intense frustration attempting CBC implementation absent foundational resources.

This implementation fidelity variation creates systematic bifurcation wherein learners in well-resourced schools receive the intended CBC experience—competency-focused, technology-enhanced, learner-centred education developing 21st-century skills—whilst peers in under-resourced schools experience diluted curriculum emphasising rote memorisation and examination preparation. This pattern risks creating a two-tier system where educational quality increasingly correlates with technological privilege rather than learner ability or effort, contradicting equity principles underlying universal education provision.

Sustainability Challenges: Cyclical Disadvantage Patterns

Beyond initial acquisition, technology sustainability emerged as critical yet systematically neglected. Among schools possessing digital infrastructure, 43% reported that over half their devices were non-functional due to maintenance deficits. Primary failure modes included: hardware breakdown (screens, keyboards, batteries—mentioned by 67% of schools), software corruption (48%), virus infection (41%), obsolescence (38%), and vandalism/theft (22%). Repair timelines averaged 4.7 months where repairs occurred at all, with 37% of broken devices remaining unrepaired over 12 months.

This dysfunction pattern reflects insufficient technical support capacity: only 14% of schools employed dedicated ICT staff, whilst 76% depended on teachers with limited technical expertise to address issues beyond their competence. External technical services were either unavailable (particularly rurally—mentioned by 84% of rural schools) or prohibitively expensive relative to school budgets (cost cited as barrier by 91% of schools attempting external repairs).

Procurement systems created additional sustainability barriers. Competitive tendering processes prioritising lowest-cost suppliers often resulted in low-quality equipment with abbreviated lifespans and inadequate warranty coverage (described by 73% of public school administrators). Technology standards were often poorly specified, enabling suppliers to provide inappropriate devices. Limited vendor accountability meant post-sale support rarely materialised despite contractual requirements (reported by 81% of schools).

Successful sustainability models, observed in a small number of well-managed schools (primarily affluent private institutions), shared common features: dedicated ICT budgets (typically 8-12% of operational budgets), full-time technical staff, preventive maintenance schedules, user training emphasising device care, comprehensive insurance coverage, vendor partnerships including maintenance agreements, and strategic technology refresh cycles. However, these practices remained exceptional, largely unavailable to most schools.

These findings extend our cascade model by revealing cyclical disadvantage patterns: unsustained technology investments decay into non-functional assets within 3-5 years, potentially leaving schools worse positioned than before acquisition. This creates recurring rather than linear disadvantage trajectories, wherein schools experience repeated cycles of acquisition, decay, and dysfunction rather than progressive improvement.

Theoretical and Policy Implications

These findings extend existing theoretical frameworks in several ways. First, they empirically demonstrate cascading inequities wherein initial infrastructure gaps compound through skills deficits into divergent outcomes—advancing beyond static conceptualisations of digital divides to dynamic models showing gap amplification over time. The significant correlation between infrastructure and competencies ($r=0.58$, $p<0.001$) combined with both factors' independent prediction of outcomes supports this cascade mechanism.

Second, interaction effects reveal multiplicative disadvantage patterns, particularly affecting rural public schools. The significant location × school type interaction ($F=18.76$, $p<0.001$) demonstrates that disadvantages compound rather than accumulate additively, suggesting that addressing educational equity requires recognising compound rather than additive discrimination effects. Simple additive models would underestimate the severity of disadvantage experienced by multiply-marginalised schools.

Third, findings demonstrate teacher capacity as critical mediating variable between infrastructure and outcomes. Whilst infrastructure predicts implementation fidelity ($\beta=0.31$, $p<0.001$), teacher competencies show stronger prediction ($\beta=0.42$, $p<0.001$), and the significant interaction term ($\beta=0.15$, $p<0.01$) indicates that infrastructure effects depend substantially on teacher capacity to utilise available resources effectively. This suggests that infrastructure-centric policies may misallocate resources by underinvesting in human capacity development.

Fourth, sustainability emerges as distinct dimension creating cyclical disadvantage—a contribution not previously recognised in competency-based curriculum implementation literature. The finding that 43% of schools reported majority non-functional devices despite having acquired infrastructure indicates that provisioning absent sustainability systems merely postpones rather than solves resource gaps.

Policy implications suggest that addressing digital divides requires coordinated interventions across infrastructure, teacher capacity, content development, and sustainable support systems simultaneously. Infrastructure provision absent complementary investments in human capacity and maintenance systems proves insufficient and potentially counterproductive. Moreover, equity-focused policy must recognise interaction effects, targeting resources specifically to contexts experiencing compound disadvantage (particularly rural public schools) rather than assuming uniform interventions suffice.

The finding that teacher competencies demonstrate stronger prediction of implementation quality than infrastructure availability ($\beta=0.42$ versus $\beta=0.31$) suggests that professional development investments may yield greater returns than additional infrastructure procurement in contexts where basic infrastructure exists but teacher capacity constrains utilisation. This has direct implications for budget allocation priorities.

Study Limitations and Future Research Directions

Several limitations warrant acknowledgement and suggest future research directions. First, the cross-sectional design precludes causal inference; whilst regression analysis identifies predictive relationships, causation cannot be definitively established. The observed associations between infrastructure, competencies, and implementation quality may reflect unmeasured confounding variables such as school management quality or community socioeconomic status. Longitudinal research tracking schools over time as they acquire infrastructure and teachers develop competencies would strengthen causal claims and illuminate temporal dynamics.

Second, self-reported data on teacher competencies and technology integration may reflect social desirability bias, potentially overestimating actual proficiency levels. Future research incorporating objective competency assessments (e.g., performance-based tasks) and direct usage monitoring (e.g., learning management system analytics) would enhance validity and provide more accurate measures of actual versus perceived capabilities.

Third, whilst 15 counties provided reasonable geographical representation, sampling within counties employed convenience rather than probability methods, potentially limiting generalisability to Kenya's full diversity. Future research employing probability sampling across all 47 counties would strengthen external validity claims. Additionally, the study focused on junior secondary schools; patterns may differ in primary or senior secondary contexts.

Fourth, the study examined digital divides at a particular CBC implementation moment (2024); as implementation matures and infrastructure expands, patterns may shift. Repeated cross-sectional assessments or longitudinal tracking would illuminate temporal dynamics and allow evaluation of policy interventions' effectiveness.

Fifth, measurement of implementation fidelity relied primarily on observational assessments rather than direct measurement of learner outcomes. Future research directly linking digital resource availability to learner achievement, competency development, and post-schooling success would provide critical evidence regarding ultimate educational impacts.

Future research should investigate: longitudinal trajectories of digital divide evolution and whether gaps widen, narrow, or persist over time; comparative effectiveness of different professional development models in

developing teacher technology integration capacity; impact of specific infrastructure interventions on learning outcomes using experimental or quasi-experimental designs; and sustainability model effectiveness across diverse contexts. Additionally, research examining learner perspectives, digital wellbeing concerns, and equity in home technology access would complement this study's school-focused analysis.

CONCLUSION

This study assessed digital resource gaps in Kenya's junior secondary schools implementing the Competency-Based Curriculum, examining how disparities relate to implementation fidelity. Findings reveal substantial systematic inequities, with significant differences between school types and locations creating profoundly unequal educational experiences.

Multiple regression analysis demonstrated that teacher digital competencies ($\beta=0.42$, $p<0.001$) and infrastructure availability ($\beta=0.31$, $p<0.001$) significantly predict CBC implementation quality, explaining 59% of outcome variance. Interaction effects indicate multiplicative disadvantage for rural public schools, which experience compound effects exceeding what additive models would predict. These patterns suggest cascading inequities wherein infrastructure gaps compound through skills deficits into divergent learning outcomes.

Theoretically, findings extend van Dijk's multi-dimensional digital divide framework by empirically demonstrating cascade effects and interaction patterns not previously documented in competency-based curriculum contexts. The emergence of sustainability as distinct dimension creating cyclical disadvantage represents a further theoretical contribution, showing how unsustained investments create recurring rather than linear disadvantage trajectories.

Practically, findings indicate that infrastructure-centric policies may misallocate resources by underinvesting in teacher capacity development and sustainability systems. The finding that teacher competencies demonstrate stronger prediction of implementation quality than infrastructure availability suggests that professional development investments may yield greater returns than additional infrastructure procurement where basic infrastructure exists but utilisation remains constrained. Addressing digital divides requires coordinated interventions across material, human, and institutional dimensions simultaneously rather than sequential approaches prioritising visible infrastructure over less tangible capacity building.

Policy recommendations emerging from this research include: (1) establishing comprehensive teacher professional development systems emphasising pedagogical integration rather than basic operations; (2) developing infrastructure standards with explicit sustainability requirements including maintenance budgets, technical support, and refresh cycles; (3) targeting equity-focused resources specifically to contexts experiencing compound disadvantage (rural public schools) rather than assuming uniform interventions suffice; (4) creating national educational technology ecosystems addressing procurement, content development, connectivity, and technical support coordinately; and (5) establishing monitoring and evaluation systems tracking not merely infrastructure acquisition but actual utilisation and learning outcomes.

The study's limitations—particularly its cross-sectional design, reliance on self-reported data, and sampling constraints—suggest findings should be interpreted as indicative rather than definitive. Nevertheless, consistent patterns across quantitative, qualitative, and observational data provide reasonable confidence in core conclusions regarding systematic inequities threatening CBC's equity objectives.

Ultimately, this research demonstrates that technology integration absent equity safeguards risks exacerbating rather than ameliorating educational stratification. Unless substantial, coordinated interventions address compound disadvantages affecting rural public schools, technology may become a new dimension of educational inequality rather than the equalising force envisioned in curriculum reform frameworks. The emergence of two-tier CBC implementation—wherein educational quality increasingly correlates with technological privilege—contradicts fundamental equity principles underlying universal education provision and requires urgent policy attention.

As Kenya continues CBC implementation and potentially expands to additional grade levels, addressing digital resource gaps must become central rather than peripheral policy priority. The window for preventive intervention remains open but narrowing: as technology becomes increasingly embedded in curriculum delivery, assessment, and competency development, learners systematically excluded from meaningful digital engagement face progressively greater disadvantage. Ensuring equitable educational outcomes requires recognising that educational technology equity extends beyond hardware provision to encompass teacher capacity, sustainable support systems, appropriate content, and coordinated ecosystem development—dimensions requiring sustained investment and political commitment

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