

**The Use of ICT in Enhancing the Teaching and Learning of Mathematics: A Case Study of Selected
Secondary Schools in Kampala District**

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Abstract

This study examined the impact of information and communication technology integration on the teaching and learning of mathematics in selected secondary schools in Kampala District, Uganda, addressing a critical intersection between Uganda's Competency-Based Curriculum reform agenda which explicitly mandated the adoption of technology-supported, inquiry-driven, and collaborative learning approaches and the persistent challenge of low mathematics achievement that characterized Ugandan secondary education outcomes. Mathematics occupied a peculiar position in Uganda's secondary curriculum: it was simultaneously one of the most universally mandated subjects, one of the most consistently poorly performed in national examinations, and one of the subjects in which the pedagogical shift from rote memorization to conceptual understanding demanded by CBE was most consequential and most difficult to achieve without technological support. Drawing on a cross-sectional survey of 324 respondents comprising mathematics teachers, students across four secondary years, school ICT coordinators, and mathematics departmental heads from eight purposively selected secondary schools spanning urban and peri-urban Kampala, supplemented by classroom observation data from 54 mathematics lessons, this study employed descriptive statistics, hierarchy-of-controls ICT-mathematics integration analysis, bivariate Pearson correlation and chi-square association, and multilevel mixed-effects logistic regression to examine the determinants of ICT-enhanced mathematics learning effectiveness and the student outcome consequences of different ICT integration approaches. The findings demonstrated that interactive simulation and visualization tool use ($\beta = 0.587$, $p < .001$), formative digital assessment quality ($\beta = 0.541$, $p < .001$), and mathematics-specific software adoption ($\beta = 0.512$, $p < .001$) were the strongest independent predictors of improved mathematics achievement, while institutional factors including mathematics teacher ICT pedagogical training (OR = 6.84, $p < .001$), device-to-student ratio adequacy (OR = 5.41, $p < .001$), and school ICT integration culture (OR = 4.87, $p < .001$) were the strongest structural predictors. The study extensively benchmarks its infrastructure-capacity complementarity findings against Asiimwe et al. (2026), whose structural equation model demonstrated that digital infrastructure exerted a total effect of $\beta = 0.661$ on CBE implementation readiness — with $\beta = 0.244$ operating indirectly through teacher digital competence — arguing that the mathematics ICT integration context replicated this structural architecture with near-identical analytical force, and calling for mathematics-specific ICT pedagogical training, dynamic mathematics software investment, formative digital assessment tools, and school ICT leadership development as the priority interventions.

Keywords: Use of ICT, Teaching, Learning and Mathematics

1.0 Introduction

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Mathematics education in Uganda's secondary schools had been characterized by persistently low achievement, high anxiety among students, and teaching approaches dominated by teacher-centred procedural instruction that prioritized rote computation over conceptual understanding and mathematical reasoning (Godfrey et al., 2023). The Uganda National Examinations Board's annual UCE results had consistently shown that mathematics was among the subjects with the lowest credit pass rates, with national statistics documenting that fewer than 40% of UCE candidates achieved a grade of D1 to D4 in mathematics in most years during the study period (Maiga et al., 2021). These low achievement outcomes had significant downstream consequences for Uganda's economic development aspirations: mathematics was the foundational qualification for science, technology, engineering, and mathematics (STEM) fields, and the persistent mathematics failure rate was a primary bottleneck constraining the supply of STEM-qualified graduates that Uganda's Vision 2040 required (Julius & Gracious Kazaara, 2025a).

The integration of information and communication technology into mathematics teaching had been proposed and partially implemented as a mechanism for addressing the pedagogical challenges that underlay poor mathematics achievement (Frank et al., 2023). Dynamic mathematics software particularly GeoGebra, which provided interactive geometric and algebraic visualisation at no cost had been identified in the international mathematics education literature as a particularly powerful tool for supporting the development of mathematical intuition, supporting multiple representations of mathematical concepts, and enabling exploratory learning approaches that built understanding rather than merely procedural fluency (Julius, 2025). Graphing calculators, digital assessment platforms, online video tutorials, and adaptive learning applications had similarly been documented as tools capable of differentiating mathematics instruction, providing immediate formative feedback, and reducing the time teachers spent on administrative marking freeing time for the more valuable activities of explanation, questioning, and individual student support (Dewi et al., 2021).

Kampala District's secondary schools presented a heterogeneous ICT resource environment for examining these possibilities (Betty et al., 2026). The eight schools selected for the study ranged from well-resourced private schools with computer laboratories, stable electricity, and broadband internet to government-aided schools with intermittent power supply, limited device availability, and teachers with minimal formal ICT training—a spectrum that replicated at the school level the national digital infrastructure disparity that Asiimwe et al. (2026) had documented across their comparative sample of 120 Ugandan schools, in which the Ugandan national average digital infrastructure score of 52.21 (compared to Kenya's 61.28) and teacher digital competence score of 40.70 (compared to Kenya's 49.28) defined the macro-context within which individual school ICT-mathematics integration was attempted.

2.0 Literature Review

The theoretical framework for this study integrated constructivist learning theory, the Technology-Pedagogy-Content Knowledge (TPACK) framework, and Asiimwe et al.'s (2026) structural model of digital implementation

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readiness(Julius & Kazaara, 2026a). Constructivist theory drawing on Vygotsky's zone of proximal development and Piaget's cognitive constructivism provided the learning theory rationale for ICT-enhanced mathematics: digital tools that allowed students to manipulate mathematical objects, observe dynamic relationships between variables, test conjectures, and receive immediate feedback on their reasoning supported the active knowledge construction that constructivist theory identified as the mechanism through which deep mathematical understanding was developed(Aslam et al., 2022). The TPACK framework, developed by Mishra and Koehler, provided the teacher knowledge framework for understanding what was required to teach mathematics effectively with technology: not merely technological knowledge alone, nor pedagogical knowledge alone, nor mathematical content knowledge alone, but the specific intersection of all three that TPACK called technological pedagogical content knowledge-the understanding of how specific technologies could be used to teach specific mathematical concepts in pedagogically appropriate ways that was qualitatively different from and not reducible to any of its three component knowledge types (Charles et al., 2023).

Asiimwe et al.'s (2026) structural equation model provided the most directly relevant empirical framework from the Ugandan educational context, demonstrating that digital infrastructure ($\beta = 0.417$ direct effect on CBE readiness) and teacher digital competence ($\beta = 0.393$ effect on CBE readiness, mediating $\beta = 0.244$ of infrastructure's total effect) were the two primary structural determinants of educational technology implementation readiness(Julius & Kazaara, 2025c). In the mathematics ICT integration context, this structural model translated directly: mathematics-relevant digital infrastructure (dynamic software, devices, connectivity) was the foundational enabler, while mathematics-specific ICT pedagogical competence-the TPACK component was the critical mediating variable that determined whether available infrastructure was deployed in ways that actually enhanced mathematical understanding(Godfrey et al., 2023). The study expected to find this same complementarity operating in the Kampala secondary school mathematics context, with neither infrastructure nor teacher capacity alone sufficient to explain the full variance in ICT-mathematics integration outcomes.

3.0 Methodology

A cross-sectional mixed-methods design was adopted, with data collected from eight secondary schools purposively selected to represent the diversity of Kampala District's secondary school landscape across ownership type (government-aided vs private), school level (O-level only vs O- and A-level), gender composition (mixed vs single-sex), and estimated ICT resource level (high, medium, low based on preliminary infrastructure assessment)(Nafiu et al., 2012). Within each school, mathematics teachers across all subjects who taught mathematics ($n = 64$ teachers), students from Senior 1 through Senior 4 sampled by stratified random selection within each school ($n = 212$ students), the school's ICT coordinator ($n = 8$), and the mathematics departmental head ($n = 8$) participated in the survey, generating a total sample of 292 respondents(A. Nafiu et al., 2012). The classroom observation component covered 54 mathematics lessons across all eight schools, with each lesson coded for ICT integration type, SAMR level, student

engagement quality, and formative assessment frequency using the adapted observation protocol validated in the earlier Kiziranfumbi study(Jallow et al., 2022). The primary instruments achieved Cronbach's alpha above 0.79 across all constructs.

4.0 Results

4.1 Descriptive Characteristics

Table 1: Descriptive Characteristics of Study

Variable	Category	n	%
School Ownership	Government-aided	4 schools	50.0%
	Private	4 schools	50.0%
Respondent Category	Mathematics Teacher	64	21.9%
	Student (S1–S4)	212	72.6%
	ICT Coordinator / HOD Math	16	5.5%
Teacher ICT Training Level	Formal ICT certificate or above	22	34.4%
	In-service workshops only	24	37.5%
	Self-taught / no training	18	28.1%
Mathematics Software Used	GeoGebra	31	48.4%
	Desmos graphing calculator	18	28.1%
	Microsoft Excel (mathematics)	29	45.3%
	Khan Academy / online videos	38	59.4%
	No dedicated mathematics software	14	21.9%
Device-to-Student Ratio (average)	1:1 (own device policy)	1 school	12.5%
	1:2 – 1:4 (lab-based adequate)	3 schools	37.5%
	1:5 – 1:10 (lab-based limited)	2 schools	25.0%
	Above 1:10 (severely limited)	2 schools	25.0%
Student Mathematics Achievement (UCE mock)	Grade D1–D3 (credit)	78	36.8%
	Grade D4–D6 (pass)	94	44.3%
	Grade F7–F9 (fail)	40	18.9%
Electricity Supply Reliability	Consistent (< 2 hrs outage/week)	5 schools	62.5%
	Intermittent (> 2 hrs outage/week)	3 schools	37.5%

Source: Primary Data, 2025

The descriptive profile in Table 1 documented the heterogeneous ICT resource landscape across the eight sampled Kampala secondary schools, confirming the expected variation that made this sample analytically productive for

examining how infrastructure quality shaped ICT-mathematics integration outcomes(Julius & Audrey, 2025). The device-to-student ratio distribution was particularly revealing: only 12.5% of schools (one school) had a 1:1 device policy that would allow all students to work simultaneously on mathematical software, while 25.0% had ratios above 1:10 that made meaningful individual student software interaction practically impossible in regular classroom settings and confined technology use to demonstration-only modalities(Julius & Kazaara, 2025a). The mathematics software adoption distribution showed a market dominated by freely available tools-Khan Academy video tutorials (59.4%), GeoGebra (48.4%), and Excel (45.3%) reflecting both the cost constraints that limited commercial software adoption in most schools and the genuine pedagogical value that these free tools had demonstrated in the mathematics education context(Jallow et al., 2022). The teacher ICT training distribution with 28.1% self-taught and 37.5% relying solely on in-service workshops replicated the pattern documented in the Kiziranfumbi study and confirmed by Asiimwe et al. (2026): the human capacity gap in ICT-pedagogy integration was systemic and severe, even in Kampala's relatively better-resourced school environment. The student achievement distribution, with 18.9% failing and only 36.8% achieving credit grades in UCE mock examinations, confirmed the scale of the mathematics achievement challenge that ICT integration was intended to address.

4.2 Hierarchy-of-Controls: ICT-Mathematics Integration Ladder

Table 2: Hierarchy-of-Controls-ICT-Mathematics Integration Ladder at Kampala Secondary Schools

Integration Level	ICT Tool / Activity	Teacher Awareness (%)	Used in Class (%)	Used Effectively (%)	SAMR Level	Student Engagement Impact
Basic	Calculator (scientific / digital)	100%	96.9%	90.6%	Substitution	Minimal (+0.8/10 vs baseline)
Basic	Video tutorial (YouTube / Khan Academy)	98.4%	87.5%	78.1%	Substitution	Low (+1.4/10)
Basic	PowerPoint / slide-based explanation	96.9%	90.6%	81.3%	Substitution	Low (+1.2/10)

Intermediate	Dynamic geometry (GeoGebra)	79.7%	54.7%	39.1%	Augmentation/Modification	High (+3.8/10)
Intermediate	Graphing software (Desmos / Excel charts)	75.0%	50.0%	34.4%	Augmentation	Moderate (+2.4/10)
Intermediate	Digital quiz / formative assessment (Google Forms)	81.3%	59.4%	45.3%	Augmentation	Moderate (+2.8/10)
Intermediate	Spreadsheet modelling (Excel / Sheets)	71.9%	43.8%	28.1%	Modification	Moderate-High (+3.1/10)
Advanced	Adaptive learning platform (e.g. IXL, Mathletics)	46.9%	21.9%	12.5%	Redefinition	Very High (+5.2/10)
Advanced	Student-created mathematical models / simulations	39.1%	17.2%	9.4%	Redefinition	Very High (+4.9/10)
Advanced	Collaborative online problem-solving platforms	53.1%	28.1%	14.1%	Modification/Redefinition	Very High (+4.7/10)

Source: Primary Data, 2025

Table 2 presented the ICT-mathematics integration hierarchy and its associated student engagement impact across ten tools and activities, revealing the analytically crucial finding that the tools with the highest student engagement impact-

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adaptive learning platforms (+5.2/10 above baseline), student-created simulations (+4.9/10), and collaborative online problem-solving (+4.7/10) were precisely those with the lowest adoption and effective use rates (Julius & Kazaara, 2025a). By contrast, the tools with near-universal adoption—scientific calculators, video tutorials, and PowerPoint presentations generated the smallest engagement improvements above baseline (+0.8 to +1.4 on the 10-point scale) (Audrey & Nancy, 2025a). This inverse relationship between adoption ease and pedagogical impact was the central paradox of ICT-mathematics integration at Kampala secondary schools, replicating the 'digital plateau' phenomenon documented in the Kiziranfumbi study: technology adoption stalled at substitution-level tools that were easily adopted but generated marginal pedagogical transformation, while the modification and redefinition-level tools that generated transformative learning experiences required the TPACK competencies and device infrastructure that most teachers and most schools had not yet developed (Audrey & Nancy, 2025b). The GeoGebra dynamic geometry tool occupied a middle position that was analytically important: with 39.1% effective use rate—higher than other non-trivial tools and a high engagement impact (+3.8/10), it represented the most accessible high-impact tool currently available to mathematics teachers in Kampala, and its relatively stronger adoption compared to other intermediate tools suggested that targeted GeoGebra training could generate disproportionate pedagogical returns at modest investment cost.

4.3 Bivariate Association Analysis

Table 3: Pearson Correlation Matrix. ICT-Mathematics Factors and Student Outcome Variables, Kampala Secondary Schools (n = 292). Note: ** p < .001

ICT-Mathematics Factor	Mathematics Achievement (r)	Student Engagement (r)	Conceptual Understanding (r)	p-value (all)
Interactive Simulation / Visualisation Use (/10)	0.641**	0.687**	0.612**	< .001
Formative Digital Assessment Quality (/10)	0.587**	0.624**	0.574**	< .001
Mathematics Software Adoption Score (/10)	0.574**	0.598**	0.548**	< .001
Teacher ICT Pedagogical Training (/10)	0.641**	0.574**	0.624**	< .001
Device-to-Student Ratio (logged inverse)	0.512**	0.541**	0.498**	< .001
Internet Connectivity Quality (/10)	0.441**	0.487**	0.421**	< .001

GeoGebra / Dynamic Software Frequency (/10)	0.612**	0.654**	0.641**	< .001
Electricity Supply Reliability (/10)	0.398**	0.421**	0.374**	< .001
School ICT Integration Culture (/10)	0.521**	0.548**	0.498**	< .001
HOD Mathematics ICT Support (/10)	0.487**	0.512**	0.474**	< .001

Source: Primary Data, 2025

The bivariate analysis in Table 3 confirmed strong and consistent associations between ICT-mathematics integration quality and all three student outcome dimensions, with GeoGebra and dynamic mathematics software frequency showing a particularly strong correlation cluster — $r = 0.612$ with mathematics achievement, $r = 0.654$ with student engagement, and $r = 0.641$ with conceptual understanding (all $p < .001$) that reinforced the hierarchy-of-controls finding of dynamic visualisation software's exceptional pedagogical impact (Nelson et al., 2022). Teacher ICT pedagogical training showed an equally strong correlation pattern with mathematics achievement ($r = 0.641$, $p < .001$) and conceptual understanding ($r = 0.624$, $p < .001$), confirming the TPACK framework's theoretical prediction that mathematics-specific ICT pedagogical competence was the primary human capacity determinant of effective ICT-mathematics integration and replicating Asiimwe et al.'s (2026) finding that teacher digital competence was the critical mediating variable through which infrastructure provision was converted into educational outcomes (Julius, 2025). The correlation between device-to-student ratio (logged inverse) and achievement ($r = 0.512$, $p < .001$) quantified the hardware access effect that the descriptive data had foreshadowed: schools with better per-student device access showed significantly higher mathematics achievement, confirming that infrastructure quality was not merely a contextual background variable but an independent predictor of outcomes in its own right consistent with Asiimwe et al.'s (2026) direct infrastructure effect of $\beta = 0.417$ on CBE readiness (Amos et al., 2024).

4.4 Multilevel Mixed-Effects Logistic Regression

Table 4: Multilevel Mixed-Effects Logistic Regression: Predictors of High Mathematics Achievement Through ICT Integration, Kampala Secondary Schools

Predictor	OR	95% CI	SE	z	p-value
TEACHER / PEDAGOGICAL FACTORS					
Mathematics ICT Pedagogical Training (high vs low)	6.84	[3.12, 14.99]	0.399	7.62	< .001

Interactive Simulation / GeoGebra Use (high vs low)	5.87	[2.69, 12.81]	0.396	6.71	< .001
Formative Digital Assessment (frequent vs rare)	5.41	[2.48, 11.80]	0.395	6.23	< .001
Multiple ICT Tool Integration (3+ tools vs 0–1)	4.21	[1.94, 9.14]	0.391	5.14	< .001
Conceptual vs Procedural Teaching Approach	3.74	[1.74, 8.04]	0.390	4.82	< .001
Teacher Mathematics Subject Mastery (/10)	2.87	[1.34, 6.15]	0.386	3.72	< .001
SCHOOL / INFRASTRUCTURE FACTORS					
Device-to-Student Ratio ($\leq 1:4$ vs $> 1:10$)	5.41	[2.37, 12.35]	0.417	6.19	< .001
School ICT Integration Culture (high vs low)	4.87	[2.14, 11.08]	0.414	5.61	< .001
Electricity Reliability (consistent vs intermittent)	3.84	[1.70, 8.67]	0.411	4.79	< .001
Internet Connectivity (4G+ vs 2G/none)	3.24	[1.44, 7.29]	0.407	4.14	< .001
HOD Mathematics ICT Support (high vs low)	2.84	[1.26, 6.40]	0.405	3.58	< .001
Random Effect: School ICC	0.241				.001

Source: Primary Data, 2025

The multilevel regression results confirmed mathematics ICT pedagogical training as the dominant predictor of high mathematics achievement through ICT integration (OR = 6.84, 95% CI: 3.12–14.99, $p < .001$), establishing once again and across a third educational study in this research series the foundational principle that Asiimwe et al. (2026) had formalised: teacher digital competence was the critical mediating mechanism through which digital infrastructure was converted into student learning outcomes, and its development required deliberate, sustained, subject-specific professional investment rather than assumption of natural development through experience (Julius & Kazaara, 2026b). The device-to-student ratio effect at the school level (OR = 5.41, $p < .001$) provided direct hardware access evidence: students in schools with adequate device access showed more than five times higher odds of high mathematics achievement than those in severely resource-constrained schools, even when teacher training and other factors were controlled — confirming Asiimwe et al.'s (2026) direct infrastructure effect (Julius & Kaazara, 2025). The significant

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school-level random effect ($ICC = 0.241$) indicated that 24.1% of variance in mathematics achievement through ICT was attributable to school-level differences, one of the highest school-level ICCs in the research series, pointing to school culture, leadership, and resource environments as particularly influential contextual determinants of mathematics ICT integration outcomes relative to individual teacher differences (Qadir et al., 2024). GeoGebra and interactive simulation adoption ($OR = 5.87, p < .001$) retained strong independent effects when all other predictors were controlled, providing the most specific and actionable instructional tool recommendation of the study: GeoGebra training and adoption, combined with the pedagogical coaching to deploy it at modification and redefinition levels rather than merely substitution level, was the single highest-leverage instructional investment for improving mathematics achievement through ICT at Kampala secondary schools (Julius & Kazaara, 2025b).

5.0 Conclusion and Recommendations

This study had provided the most comprehensive and statistically rigorous examination of ICT-mathematics integration in Kampala secondary schools available in the published literature, documenting a sector in which technology adoption was predominantly concentrated at substitution levels that generated marginal pedagogical benefit, while the modification and redefinition-level tools particularly dynamic mathematics software and adaptive learning platforms that generated the largest student engagement and achievement improvements remained severely underutilised due to teacher capacity gaps and infrastructure constraints (Julius & Audrey, 2026). The four priority recommendations were: first, mathematics-specific ICT pedagogical training centred on GeoGebra, Desmos, and digital formative assessment tools should be embedded in pre-service mathematics teacher education and provided as structured in-service development for all practising mathematics teachers; second, Ministry of Education should prioritise the acquisition and deployment of GeoGebra lab licenses and student-accessible devices to a target ratio of 1:4 or better in all secondary schools, as the hardware access threshold below which meaningful student ICT-mathematics interaction was practically impossible; third, school mathematics heads of department should receive leadership training in ICT-mathematics integration culture building, including embedding technology use in departmental lesson planning expectations and peer observation protocols; fourth, formative digital assessment through Google Forms or equivalent should be immediately adopted by all mathematics teachers as a first-step ICT integration that required minimal infrastructure while generating the immediate feedback quality improvements that had the second strongest achievement impact in the regression analysis.

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