

## Evaluating the relationship between technological interoperability and learning efficiency among Kampala-based universities

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**Abstract:** This study investigates the relationship between interoperability and learning enhancement among Kampala-based universities. Using a cross-sectional survey of 293 students from three universities, data were collected via structured questionnaires and analyzed using descriptive statistics, Pearson correlation and regression. Results revealed **pedagogy-focused interoperability** ( $\beta=4.024, p<0.01$ ) and **secure data collaboration** ( $\beta=3.832, p<0.01$ ) as paramount predictors of learning gains, correlating strongly with multimedia engagement ( $r=0.629$ ) and AI adaptation ( $r=0.630$ ). Conversely, **AI analytics** showed significant influence ( $\beta=2.491, p<0.01$ ) but low student acceptance (mean=2.26), indicating a perception-efficacy disconnect, while **infrastructure gaps** marginalized personalization's impact ( $\beta=1.545, p=0.059$ ). The study concludes that interoperability enhances learning most effectively when prioritizing pedagogical alignment, security, and equitable access, yet infrastructure deficits and cultural skepticism toward AI limit its potential. **Developing offline-capable, low-bandwidth tools, Co-designing culturally responsive AI and Policy frameworks** integrating technical standards with socio-technical support are recommended.

**Keywords:** Technological interoperability, learning efficiency

### Background

Digital transformation continues to redefine the landscape of higher education across Africa, with universities increasingly adopting integrated digital systems to enhance pedagogy, administration, and student engagement. At the core of this evolution is technological interoperability, the seamless ability of different platforms, systems, and applications to exchange and utilize data across institutional and functional boundaries (Ifinedo et al., 2021). In developed contexts, interoperability supports personalized learning, smooth content delivery, and advanced models like Learning Analytics and AI-enhanced feedback systems (Zawacki-Richter et al., 2019; Gašević et al., 2015). In Uganda, and particularly among Kampala-based universities, the implementation of interoperability remains fraught with challenges. Bandwidth constraints, inconsistent internet access, and under-resourced IT infrastructure limit the integration of digital systems (Bagarukayo et al., 2022). Institutions often operate fragmented digital ecosystems using disparate, non-standardized learning management systems (LMSs), hindering data portability and system-wide functionality (UNESCO, 2024). Moreover, the socio-cultural relevance of imported technologies is often questionable, as many tools fail to align with local linguistic and pedagogical contexts (Ndlovu, 2021). Despite these challenges, some evidence suggests that improved interoperability can enhance educational outcomes. McGreal et al. (2023) demonstrate that integrating tools like Moodle and Google Workspace through APIs can boost student engagement and ease access to learning materials. Similarly, Kihzoza et al. (2020) observed increased collaboration and security in Tanzanian universities that adopted interoperable systems. In Uganda, Muwanga et al. (2023) note the growing use of cloud-based tools, but highlight that these are often deployed in isolation, limiting their impact. Furthermore, the increasing relevance of micro-credentials, open educational resources (OERs), and hybrid learning models in the post-COVID-19 era calls for interoperable systems that can support cross-institutional recognition of learning achievements and the development of unified learner profiles (Trotter et al., 2023; Ngugi et al., 2022). Yet, the extent to which interoperability contributes to learning enhancement within the constraints of Uganda's higher education environment remains underexplored. While prior studies have highlighted the benefits of isolated digital tools and platforms, there is a lack of empirical research examining how students perceive the role of interoperability, and how different interoperability

components collectively influence learning efficiency in the Ugandan university context. Therefore, this study aimed: i) to assess students’ perceptions of the role of technological interoperability in enhancing learning, ii) to evaluate the relationship between technological interoperability and learning enhancement among Kampala-based universities, and iii) to determine the influence of key interoperability components on learning efficiency.

**METHODOLOGY**

**Study area**

The study was conducted in three selected universities namely: Metropolitan International University (Latitude: 0.3408; Longitude:32.5410), Kampala International University (Latitude:0.2944; Longitude:32.6040) and Kyambogo University (Latitude:0.350000; Longitude:32.630000) in Kampala metropolitan area. Metropolitan International University is located approximately 300 meters along Nakibinge Road off Kampala-Hoima Road (Google, 26 December 2020), whereas, Kyambogo university is located on on Kyambogo Hill, approximately 8 kilometers east of Kampala's central business district. Kampala International University's (KIU) is located in Kansanga, a neighborhood in the Makindye Division of Kampala, Uganda. It's approximately 7 kilometers southeast of Kampala's central business district, along the road to Ggaba.

**Research Design**

The study adopted a cross-sectional survey research design due to its high magnitude of precision and accuracy (Ambetsa et al., 2020). The design allowed for collection of data at a single point thus saving on resources and time (Wambua et al., 2019). Ambetsa et al. (2020) explains that cross sectional survey helps researchers describe populations within the study area in regard to the findings and define the extent to which the results relate to the sampled population. The design employs both quantitative and qualitative data in collecting and analyzing data with an intent of having one phase of the mixed method building into another. It allows for data collected from both quantitative and qualitative to be converged or integrated at the discussion stage of the study (Creswell & Plano-Clark, 2018).

**Study population and sampling design**

The study population consisted of students from three selected universities (Metropolitan International University, Kampala International University and Kyambogo University (ARs offices, 2020). A two-stage sampling technique was employed. The first stage was purposive selection three universities due to their location in the central part of the country where internet is more accessible and reliable compared to any other universities beyond. This was followed by simple random sampling technique that was used to select the study sample due to its representative of the population and being free from bias and prejudice (Neumann, 2012). Each student name was assigned a random number from which a sample of 293 students were randomly selected (Table 1), following procedures of Yamane (1970) as shown below;

$$Sample\ size\ (n) = \frac{N}{1+N^2e}$$

Where:

*n* = desired sample size

*N*= population size (i.e. the entire group that the study population is drawn from)

*e* = acceptable sampling error (0.05)

**Table1 1: Total number of selected student participants**

Category of respondents	Population of BA students	Sample size
Kyambogo University	500	134
Kampala International University	400	107
Metropolitan International University	195	52
<b>Total</b>	<b>1095</b>	<b>293</b>

Source: Primary data (2025)

### Data types and data collection

This study utilized cross-sectional primary data, which was gathered through a pre-tested, researcher-administered structured questionnaire. The questionnaire included items addressing students' demographic characteristics (sex, age, and university affiliation), use of ICT and duration for learning and search engines used. Additionally, a 5 pointer Likert scale ranging from " Strongly Disagree " to " Strongly agree " was employed to assess both internet availability and learning enhancement among students.

### Validity and reliability

This study used different types of validity procedures to explain how well the collected data covered the actual area of investigation. They included: face validity, content validity, Kaiser-Meyer-Olkin (KMO) and Bartlett's Test. For reliability, this study used the Cronbach Alpha Coefficient (CAC or  $r$ ) to examine whether or not the questionnaire as an instrument was generally reliable for field study of the current study.

### Data analysis

Descriptive analysis was performed in SPSS, before the data was exported to STATA v. 14 for econometric analysis. Descriptive statistics and simple inferential statistics involved computations of means, frequency distribution and standard deviations for students' continuous and categorical characteristics, internet availability and its influence on learning enhancement. Students' perception on internet availability and its influence on learning enhancement were measured using of a 5-point Likert scale following procedures of Likert (1932). Likert-scale type of interview results in a single score that represents the degree to which a person is favorable or unfavorable with respect to the question asked (Bernard, 1994). Some questions were reverse coded to avoid bias. Each respondent was asked to indicate their extent of agreement or disagreement against each statement along a 5-point scale: very low, low, moderate, high and very high. Weights assigned to these responses were 5, 4, 3, 2, and 1 respectively. Cronbach's Alpha analysis was done to determine the reliability and internal consistency of questions regarding Students' perception on internet availability and its influence on learning enhancement (Olaniyi, 2019). Arithmetic means were calculated from the Likert scale to get the overall students' perception. Pearson correlation and regression were used to examine the relationship between inter-operation ability and learning enhancement as the dependent variable, among university students.

### Data analysis

Descriptive analysis was performed in SPSS, before the data was exported to STATA v. 14 for econometric analysis. Descriptive statistics and simple inferential statistics involved computations of means, frequency distribution and standard deviations for students' continuous and categorical characteristics, technological interoperability and the learning efficiency. Students' perception on technological interoperability and the learning efficiency among Kampala-based universities were measured using of a 5-point Likert scale following procedures of Likert (1932). Likert- scale type of interview results in a single score that represents the degree to which a person is favorable or unfavorable with respect to the question asked (Bernard, 1994). Some questions were reverse coded to avoid bias. Each respondent was asked to indicate their extent of agreement or disagreement against each statement along a 5-point scale: very low, low, moderate, high and very high. Weights assigned to these responses were 5, 4, 3, 2, and 1 respectively. Cronbach's Alpha analysis was done to determine the reliability and internal consistency of questions regarding Students' perception on technological interoperability and the learning efficiency among Kampala-based universities (Olaniyi, 2019). Arithmetic means were calculated from the Likert scale to get the overall students' perception. The data were then dichotomized to get a binary response. This was done through collapsing responses 1, 2 and 3 from the original scale to 0=disagree (negative) and 4 and 5 to 1= agree (positive), following procedures of Jeong and Lee, 2016. The rationale for rubric dichotomization was that people who answered higher than or equal to 4 were positive (agreed) while those who were green and those who scored below 4 were negative (disagreed).

Table 2: Scale collapsing scheme to generate dichotomized response data

<b>Original</b>	<b>1</b> (Very low)	<b>2</b> (Low)	<b>3</b> (Moderate)	<b>4</b> (High)	<b>5</b> (Very high)
<b>Dichotomized</b>	<b>0</b> (Disagree/ negative)			<b>1</b> (Agree/ positive)	

Pearson correlation coefficient was used to analyze the relationship between inter-operationability and learning enhancement. The binary logistic econometric model was used to assess the influence of inter-operation ability on learning enhancement among Kampala based universities as presented below;

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 \dots \dots \dots \beta_n X_n + \epsilon_i$$

Where;

Y: Dependent variable (Learning efficiency),

$\beta_0$ : Intercept,

$\beta_1$ -n: Coefficient of the explanatory variables,

X1-n: Explanatory variables (Technological interoperability).

**RESULTS AND DISCUSSION OF RESULTS**

Respondent demographics and ICT usage patterns

Results showed that the demographic distribution of respondents, skewed towards individuals aged 21–24 years (74.14%, n=215), and this aligns with global patterns in undergraduate enrollment, where younger adults dominate due to standardized tertiary education pathways (UNESCO, 2022). The underrepresentation of older age groups (e.g., 0.69% above 40 years, n=2) reflects persistent barriers to adult education, such as work-life balance challenges and institutional inflexibility, as noted in OECD (2023) reports. The slight female majority (52.78%, n=152) mirrors global trends in higher education, where women now constitute 55% of university enrollments, a shift attributed to socio-cultural and policy changes (HESA, 2023; World Bank, 2022). The predominance of Bachelor’s degree holders (85.0%, n=227) is consistent with enrollment statistics in developing and developed nations, where undergraduate programs remain the primary entry point to higher education (Altbach et al., 2022). The limited representation of postgraduate students (e.g., 1.0% PhD candidates, n=2) highlights the niche status of advanced degrees, a phenomenon linked to funding constraints and career prioritization (Nerad, 2020).

Table 2: Respondent demographics and ICT usage patterns

Variable	Category	Frequency	Percentage
Age	Below 20	29	10.00
	21 - 24	215	74.14
	25 - 30	30	10.34
	31 - 40	14	4.83
	Above 40	2	0.69
Gender	Male	136	47.22
	Female	152	52.78
Education level	Diploma	27	10.0
	Degree	227	85.0
	Masters	10	4.0
	PhD	2	1.0
Experience with computers	Less than a year	66	23

	1 to 3	114	39.72
	4 to 6	49	17.07
	More than 6	59	20.21
Use of ICT for Learning	Yes	225	78.95
	No	60	21.05
Duration of ICT for learning	Never	25	9
	6months	43	15
	6-12months	47	16
	More than a year	174	60
Search engines used	Internet Explorer	99	34.98
	Google Chrome	159	56.18
	Mozilla Firefox	9	3.18
	Microsoft Edge	16	5.65

Source: Field research, (2025)

Respondents' computer experience, with 39.72% (n=114) reporting 1–3 years of use, reflects the increasing integration of digital tools in secondary education curricula (European Commission, 2021). However, the notable proportion with over six years of experience (20.21%, n=59) suggests a subgroup with advanced digital literacy, likely influenced by early exposure to technology in both academic and personal contexts (van Laar et al., 2020). The high adoption of ICT for learning (78.95%, n=225) aligns with post-pandemic shifts toward blended and online education, as documented in global surveys by the International Association of Universities (Marinoni et al., 2022). The majority (60%, n=174) using ICT for over a year supports findings that sustained engagement with digital tools enhances self-efficacy and academic performance (Scherer et al., 2021). However, the persistence of non-users (21.05%, n=60) highlights lingering digital divides, often rooted in socioeconomic disparities or inadequate institutional support (Czerniewicz et al., 2023). Google Chrome's dominance as the preferred search engine (56.18%, n=159) correlates with its global market share (87% as of 2023) and user-friendly design for academic research (StatCounter, 2023). The residual use of internet explorer (34.98%, n=99) may reflect institutional reliance on legacy systems, despite its phased discontinuation in 2022 (Microsoft, 2022).

### Students' perception on the role of Inter-operation ability on learning enhancement

Table 3 presents results on interoperability factors influencing learning enhancement, measured on a 5-point Likert scale (SD=1 to SA=5). Students demonstrated strongest agreement that cross-platform data aggregation enables personalized learning (mean=3.69, high; 67.7% agreed/strongly agreed), recognizing seamless data integration facilitates adaptive content delivery, which aligns with global learning analytics trends (Ifinedo et al., 2021) yet holds particular resonance in African contexts where fragmented digital ecosystems hinder personalization (Bagarukayo et al., 2022).

### Students' perception on the role of Inter-operation ability on learning enhancement

Statement	SD	D	N	A	SA	Mean	Std dev	Interpretation	Ranking
Educational platforms sharing data enhance collaborative learning.	21.50	12.70	12.30	34.50	19.00	3.17	1.439	Moderate	1
Standardized formats ease learning environment transitions.	29.30	20.50	15.20	23.00	12.00	2.68	1.411	Moderate	2

AI analytics integration improves adaptive learning strategies.	43.70	21.50	10.60	14.10	10.20	2.26	1.402	Low	3
Secure protocols protect data, enable collaborative research.	16.70	13.50	22.30	28.40	19.10	3.2	1.348	Moderate	4
Automated cross-software feedback reduces delays, aiding learning.	20.20	28.00	10.30	30.50	11.00	2.84	1.347	Moderate	5
Integrated multimedia boosts engagement and knowledge retention.	17.80	23.10	19.60	24.60	14.90	2.96	1.338	Moderate	6
Cloud tools enable flexible, location-independent learning.	15.10	13.40	12.30	41.50	17.60	3.33	1.325	Moderate	7
Interoperability reduces technical barriers, prioritizes pedagogy.	14.50	9.20	15.60	40.80	19.90	3.42	1.305	High	8
Compatible tools across OS ensure equitable access.	13.30	16.10	31.90	26.20	12.50	3.09	1.205	Moderate	9
Cross-platform data aggregation enables personalized learning.	7.50	7.80	17.10	43.10	24.60	3.69	1.146	High	10

**Key:** SD-Strongly Disagree, D-Disagree, N-Neutral, A-Agree, SA-Strongly Agree

**Legend:** 4.20- 5.00 (*very high/Strongly agree*), 3.40 - 4.19 (*high/Agree*), 2.60-3.39 (*moderate/Neutral*) 1.80 -2.59 (*low/Disagree*), 1.00-1.79 (*very low/Strongly disagree*)

**Source:** Field research, (2025)

Similarly, interoperability's role in reducing technical barriers to prioritize pedagogy received high agreement (mean=3.42; 60.7% agreed/strongly agreed), reflecting Ugandan findings where technical incompatibilities disrupt pedagogical engagement (Muwanga et al., 2023). Moderate agreement emerged for cloud-enabled location-independent learning (mean=3.33; 59.1% agreed/strongly agreed), underscoring how cloud interoperability addresses East Africa's infrastructure gaps through offline synchronization and low-bandwidth access (UNESCO, 2024; Muwanga et al., 2023), alongside secure protocols enabling collaboration (mean=3.20; 47.5% agreed/strongly agreed), mirroring Tanzanian evidence where encrypted data sharing boosts cross-institutional research (Kihoza et al., 2020), and educational platforms sharing data (mean=3.17; 53.5% agreed/strongly agreed), valued in African universities' multi-institutional collaborations (McGreal et al., 2023). Conversely, AI analytics integration received low agreement (mean=2.26; 65.2% disagreed/strongly disagreed), reflecting skepticism toward culturally misaligned tools and algorithmic colonialism concerns (Ndlovu, 2021), contrasting with Western AI acceptance (Zawacki-Richter et al., 2019). These patterns reveal infrastructure limitations amplify interoperability needs, as bandwidth constraints make lightweight tools essential (Bagarukayo et al., 2022), while security's moderate rating masks its foundational role in enabling collaboration post-breach (Kihoza et al., 2020), and students prioritize pedagogical outcomes like personalization over technical mechanisms (Sentongo et al., 2024).

### Relationship between Inter-operation ability on learning enhancement

Table 4 reveals significant Spearman correlations among interoperability variables, with security enabling collaboration demonstrating strong relationships with AI-enhanced adaptation ( $r= 0.630, p < 0.01$ ) and multimedia boosting engagement ( $r = 0.510, p < 0.01$ ), indicating that secure

Table: Relationship between Inter-operation ability on learning enhancement

Variables	DEC	FET	AEA	SEC	ARD	MBE	CEF	IPP	CEA	AEP
Data enhances collaboration (DEC)	1.000	-	-	-	-	-	-	-	-	-
Formats ease transitions (FET)	0.287**	1.000	-	-	-	-	-	-	-	-
AI enhances adaptation (AEA)	0.182**	0.590**	1.000	-	-	-	-	-	-	-
Security enables collaboration (SEC)	0.270**	0.583*	0.630**	1.000	-	-	-	-	-	-
Automation reduces delays (ARD)	0.091**	0.291**	0.242**	0.263**	1.000	-	-	-	-	-
Multimedia boosts engagement (MBE)	0.226**	0.548*	0.527**	0.510**	0.311*	1.000	-	-	-	-
Clouds enable flexibility (CEF)	0.159**	0.361**	0.373**	0.373**	0.137	0.237**	1.000	-	-	-
Interoperability prioritizes pedagogy (IPP)	0.252**	0.459**	0.577*	0.595**	0.251**	0.629**	0.420*	1.000	-	-
Compatibility ensures access (CEA)	0.109**	0.217**	0.240**	0.285*	0.044**	0.046*	0.083**	0.281*	1.000	-
Aggregation enables personalization (AEP)	0.175*	0.492**	0.407**	0.567*	0.263**	0.433**	0.322**	0.546*	0.328*	1.000

\*\* Correlation is significant at the 0.01 level (2-tailed), \* Correlation is significant at the 0.05 level (2-tailed).

Source: field survey (2025)

data protocols serve as foundational enablers for adaptive and multimedia-enhanced learning, consistent with Tanzanian evidence where encrypted systems increased cross-institutional research collaboration by 41% (Kihzoza et al., 2020). Similarly, interoperability prioritizing pedagogy correlated strongly with multimedia engagement ( $r = 0.629, p < 0.01$ ), reinforcing findings from Kenya where standard-compliant multimedia reduced technical disruptions and improved pedagogical flow (Obonyo, 2022). Conversely, compatibility ensuring access showed negligible correlations with automation reducing delays ( $r = 0.044, p < 0.01$ ) and multimedia engagement ( $r = 0.046, p < 0.05$ ), suggesting that cross-OS compatibility alone cannot resolve systemic barriers to automated feedback or resource-intensive multimedia, aligning with UNESCO’s (2024) diagnosis of Africa’s infrastructure gaps. The weak link between data-enhanced collaboration and automation ( $r = 0.091, p < 0.01$ ) further underscores that interoperability’s collaborative benefits may not inherently streamline feedback workflows without pedagogical integration, as observed in Ugandan contexts where tool compatibility failed to reduce learning delays without instructor mediation (Mwangi et al., 2023). These patterns collectively highlight that interoperability’s efficacy depends on interdependent variables particularly security and pedagogical alignment while fragmented solutions (e.g., compatibility without automation) yield minimal impact.

**Influence of Inter-operation ability on learning enhancement**

Poisson regression analysis ( $R^2 = 0.689$ ) demonstrates that interoperability prioritizing pedagogy exerts the strongest influence on learning enhancement (Coef. = 4.024,  $p < 0.01$ ), validating Ugandan research positioning pedagogical design as the core driver of effective interoperable systems (Sentongo et al., 2024), followed closely by security-enabled collaboration (Coef. = 3.832,  $p < 0.01$ ), which McGreal et al. (2023) similarly identified as increasing collaborative research outputs by 33% across African universities. Notably, AI-enhanced adaptation significantly predicts learning gains (Coef. = 2.491,  $p < 0.01$ ) despite low student acceptance (Table 1), suggesting its efficacy depends on implementation quality rather than perception, a paradox aligning with Zawacki-Richter et al.'s (2019) global review of "invisible" AI successes. Moderate influences include cloud-enabled flexibility (Coef. = 2.035,  $p < 0.01$ ) and multimedia engagement (Coef. = 2.130,  $p < 0.01$ ), corroborating Obonyo's (2022) findings in Kenya where interoperable multimedia elevated engagement, while compatibility ensuring access shows weaker influence (Coef. = 1.765,  $p = 0.014$ ), indicating cross-OS tools alone cannot overcome deeper infrastructure inequities without complementary interventions (Bagarukayo et al., 2022). Crucially, data aggregation enabling personalization is marginally non-significant (Coef. = 1.545,  $p = 0.059$ ), reflecting UNESCO's (2024) observation that Africa's connectivity gaps limit personalized learning's potential despite high student demand (Table 5), thereby underscoring that interoperability's impact hinges on contextual enablers like infrastructure and pedagogical integration.

**Table 5: Influence of Inter-operation ability on learning enhancement**

Inter-operation ability	Learning enhancement			P>z
	Coef.	Std. Err.	z	
Formats ease transitions	2.126	0.3334	4.810	0.000**
AI enhances adaptation	2.491	0.3771	6.030	0.000**
Security enables collaboration	3.832	1.1183	4.600	0.000**
Automation reduces delays	1.657	0.3290	2.550	0.011*
Multimedia boosts engagement	2.130	0.3998	4.030	0.000**
Clouds enable flexibility	2.035	0.3826	3.780	0.000**
Interoperability prioritizes pedagogy	4.024	0.7815	7.170	0.000**
Compatibility ensures access	1.765	0.4076	2.460	0.014*
Aggregation enables personalization	1.545	0.3564	1.890	0.059
Constant	0.000	0.0001	-8.960	0.000**

\*\* Statistically significant at .01, \* Statistically significant at .05  $R^2=0.689$ , adjusted  $R^2=0.665$

Source: Field survey (2025)

**CONCLUSION**

In conclusion, the study confirms that interoperability demonstrably enhances learning in African higher education primarily through pedagogically aligned design and secure data collaboration, which reduce technical barriers and enable cross-institutional engagement, yet its efficacy is constrained by infrastructure gaps limiting personalized learning and cultural skepticism toward AI adaptation despite its predictive power, necessitating context-responsive implementations that prioritize pedagogy, security, and equitable access alongside localized AI integration.

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