UtilitasMathematica

ISSN 0315-3681 Volume 122 (2), 2025

E-Learning Effectiveness and Efficiency in Kassala and Gedaref Universities: An IS-Impact Evaluation

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Abstract

In low-resource settings with intermittent power and connectivity, e-learning must translate technical and informational qualities into institutional value. This cross-sectional study evaluates how e-learning creates organizational impact in two Sudanese public universities (Kassala, Gedaref) using the IS-Impact model. Survey data from N = 412 students and faculty were analyzed with covariance-based SEM (WLSMV). Model fit was good. System Quality (SQ) strongly predicted Information Quality (IQ), and both IQ and SQ improved Individual Impact (II); in turn, II strongly drove Organizational Impact (OI). Direct paths from SQ/IQ to OI were non-significant, while indirect effects via II were substantial (e.g., IQ→II→OI = 0.41; SQ→II→OI = 0.16), indicating a full/semi-full mediation pattern. Connectivity and electricity reliability amplified quality→II links, underscoring the importance of engineering for uptime and low-bandwidth delivery. Results were invariant across roles and universities. Implication: institutions should prioritize editorial pipelines that raise IQ, harden SQ for mobile/low bandwidth, and invest in reliability measures (offline caching, micro-servers, basic power backup), monitored through actionable KPIs. Institutional approvals were obtained. Index Terms— IS-Impact; E-learning; System Quality; Information Quality; Low bandwidth; Sudan.

Index Terms— E-learning effectiveness and efficiency; IS-Impact model; System quality; Information quality; Learning management system (LMS); Kassala and Gedaref Universities (Sudan).

1. Introduction

E-learning has become a strategic instrument for safeguarding instructional continuity in crisis-affected and low-resource settings; yet its benefits remain uneven and highly contingent on local infrastructure constraints such as connectivity and power reliability [1], [2]. In such contexts, effectiveness depends less on media “richness” and more on robust, low-bandwidth delivery that reliably reaches learners.

Sudan exemplifies these constraints. During 2024–2025, repeated Internet disruptions and severe power outages affected service availability across the country—including the eastern states of Gedaref and Kassala—complicating the operation of higher-education systems [3], [4]. Humanitarian telecommunications updates similarly document degraded network capacity due to damaged towers, electricity interruptions, and fuel shortages since April 2023 [5]. These realities make low-bandwidth-first e-learning design and dependable information systems a practical necessity rather than a stylistic choice.

To evaluate value creation under such constraints, institutions require frameworks that go beyond user satisfaction and quantify how technical and informational qualities of learning platforms translate into individual and organizational value. The IS-Impact model offers such a structure, reconceptualizing IS success as a formative, multidimensional index with four pillars: System Quality (SQ), Information Quality (IQ), Individual Impact (II), and Organizational Impact (OI) [6]. This separation of “quality” (as proxies for future benefits) from realized “impacts” supports cumulative research and actionable decision-making in higher education.

Recent work has applied or extended IS-Impact to e-learning with modern SEM toolchains, reporting good measurement fit and interpretable quality→impact pathways across higher-education settings, including comparative PLS-SEM/IPMA analyses of e-learning tools [7] and reviews emphasizing implementation barriers and enablers in emerging economies (governance, infrastructure, digital skills, equity) [8]. This evidence motivates testing (a) indirect/mediated effects whereby II links SQ/IQ to OI, and (b) moderation by infrastructural reliability—both under-examined in conflict-affected, low-bandwidth contexts.

Research gap and aim. Prior studies seldom test mediation via II together with infrastructure-reliability moderation in low-resource universities facing intermittent power and connectivity. This study addresses that gap by evaluating how e-learning creates institutional value at low bandwidth in two Sudanese public universities (Kassala and Gedaref). Using the IS-Impact model and confirmatory SEM, we: (i) validate a four-factor measurement for SQ, IQ, II, and OI; (ii) estimate structural paths to test whether II mediates quality→outcomes; and (iii) examine whether electricity and connectivity reliability strengthen or weaken these pathways. Our contribution is an evidence-based account of what to improve (system/information-quality levers) and why it matters (translation into individual and organizational outcomes) under intermittent power and limited bandwidth.

Organization. Section 2 reviews related work; Section 3 details methods; Section 4 reports results; Section 5 discusses implications and limitations; Section 6 concludes.

2. Related Work

2.1 E-learning in low-resource contexts

Universities in emerging, low-infrastructure settings face recurrent constraints—limited bandwidth, unstable electricity, device scarcity, and gaps in digital skills—that shape e-learning design and outcomes. Recent syntheses for Sub-Saharan Africa consistently rank ICT infrastructure, technical support, and student bandwidth among the most cited barriers, arguing for low-bandwidth formats and institutional support as preconditions for effectiveness [8], [10].

2.2 Sudan and neighboring evidence

Since 2023–2025, conflict-driven damage and intermittent connectivity have made sustained online delivery difficult in Sudan; documented Internet disruptions and nationwide power outages directly affected higher education, including the eastern states of Gedaref and Kassala [3], [4]. Humanitarian telecommunications updates likewise report degraded capacity due to damaged towers, electricity interruptions, and fuel shortages [5]. Sector plans highlight urgent ICT gaps and "quick wins" (e.g., solarization, platform standardization) to keep learning going [12]. Within this context, evidence from Sudanese students shows that online learning can maintain satisfaction while co-occurring with stress, underscoring the need to pair access with academic and psychosocial supports [11]. Local implementations—e.g., the University of Kassala's Moodle—illustrate on-the-ground adoption that motivates institution-specific evaluation [22].

2.3 IS-Impact in higher education and e-learning

The IS-Impact model conceptualizes IS success as a formative construct with four dimensions: System Quality (SQ), Information Quality (IQ), Individual Impact (II), and Organizational Impact (OI) [6]. Recent e-learning applications use PLS-SEM and related analyses (e.g., IPMA) to link quality dimensions to II and OI in LMS/tool contexts [7]. Reporting guidelines for SEM emphasize transparent reliability and validity evidence when modeling such relationships [13]. This stream motivates testing (a) indirect/mediated effects from quality → II → OI and (b) context moderators (e.g., infrastructure reliability) that remain under-examined in conflict-affected, low-bandwidth settings.

2.4 Measurement practices (validity and estimators)

Best practice encourages reporting multiple reliability/validity criteria and emphasizes discriminant validity checks such as HTMT/HTMT2 alongside convergent validity [13], [14]. For ordinal Likert indicators, WLSMV/DWLS estimators are recommended in covariance-based SEM; documentation and tutorials converge on WLSMV for ordered data [15], [16]. These practices inform our study's modeling and reporting choices.

2.5 Offline-first and low-bandwidth delivery patterns

Evidence from Tanzania shows that offline LMS micro-servers (e.g., Raspberry Pi) can deliver Moodle-based content without Internet; trade-offs appear in response time, connection limits, and robustness—Pi solutions often offering favorable cost/performance for small cohorts [17], [18]. Complementary guidance recommends mobile-first, asynchronous content, file-size reduction, and minimizing videoconferencing given its heavy data consumption [19], [20]. Empirical work also connects Internet stability and device access to learner satisfaction and achievement, justifying the inclusion of infrastructure quality as a contextual moderator in impact models [21].

2.6 Gap and positioning

In sum, prior work validates IS-Impact for e-learning and details constraints in African and Sudanese contexts, but few studies jointly test (i) mediation via II and (ii) moderation by infrastructure reliability within a single model for universities operating under conflict-related bandwidth and power instability. Our study addresses this gap by estimating a mediated-moderated IS-Impact model for the University of Kassala and University of Gedaref, tuned to the low-bandwidth delivery realities identified above.

3. Methodology

3.1 Study Design and Setting

We conducted a cross-sectional, explanatory study at two Sudanese public universities—University of Kassala and University of Gedaref—to evaluate how e-learning creates institutional value under low-bandwidth constraints. The theoretical lens is the IS-Impact model with four reflective first-order constructs: System Quality (SQ), Information Quality (IQ), Individual Impact (II), and Organizational Impact (OI) [6]. Reporting follows contemporary SEM guidance on transparent reliability/validity evidence [13] and discriminant validity using HTMT/HTMT2 [14]. Data collection took place March 15 – May 10, 2025, under ethics approvals UKSL-REC/EDU/2025/017 (University of Kassala) and UGDF-REC/EDU/2025/009 (University of Gedaref). Participants provided electronic informed consent; no personally identifying information was collected.

3.2 Participants and Sampling

The target population comprised active LMS users (students and faculty). We applied stratified convenience sampling by university and role. The final analytic sample was $N = 412$ (Students 78%, $n = 321$; Faculty 22%, $n = 91$). By site: Kassala 52% ($n = 214$) and Gedaref 48% ($n = 198$). Power adequacy was examined via analytical checks and sensitivity analyses for the specified SEM; with $N = 412$ and small-to-moderate target effects ($\beta \approx .20–.30$, $\alpha = .05$), power was adequate for the focal paths and indirect effects (details in Appendix A) [13]. Cases with <80% item completion or patterned/implausible responding were excluded.

3.3 Measures and Instruments

We adapted the IS-Impact instrument (Arabic/English) with 36 reflective indicators (9 per construct). Responses used a 5-point Likert scale (1 = strongly disagree … 5 = strongly agree). While IS-Impact conceptualizes overall impact formatively, our model treats SQ, IQ, II, and OI as reflective first-order factors in a confirmatory measurement model [6], [13], [14]. Full item wordings (EN/AR) appear in Appendix A. A-priori item-retention rules were set (e.g., drop if standardized loading < .50, absent theoretical justification).

Table 1 — Indicator codebook (constructs and item codes)

Construct	Code range	Short descriptor
System Quality (SQ)	SQ1–SQ9	Reliability/uptime; response time; mobile usability; error-free operation; ease of use
Information Quality (IQ)	IQ1–IQ9	Accuracy; completeness; relevance; timeliness; clarity
Individual Impact (II)	II1–II9	Study/teaching efficiency; confidence; productivity; satisfaction
Organizational Impact (OI)	OI1–OI9	Coordination; decision support; policy alignment; cost/time savings

3.4 Translation, Adaptation, and Content Validity

Forward–back translation (EN↔AR) was conducted by bilingual subject-matter experts, followed by cognitive interviews ($n \approx 12$) to assess clarity, terminology, and scale endpoints. A 5-member expert panel rated item relevance; I-CVI per item ranged 0.80–1.00 and S-CVI/Ave = 0.93 after revisions, supporting content validity prior to fielding [13].

3.5 Data Collection, Privacy, and Missing Data

Data were collected via secure online forms and supervised computer labs (where connectivity permitted) within the above timeframe. Participation was voluntary with electronic informed consent; anonymized data were stored on encrypted drives. Missing data were low at the item level; given ordinal indicators and WLSMV estimation, we used pairwise-present handling for polychoric correlations and verified robustness to listwise deletion in sensitivity checks (Appendix A). IP addresses/device identifiers were not logged.

3.6 Statistical Analysis

Analyses were performed in R 4.3.2 / lavaan 0.6-17. Because indicators are ordinal (Likert), we used WLSMV (diagonally weighted least squares with mean- and variance-adjusted χ^2), as recommended for ordered categorical data in covariance-based SEM [15], [16]. Robustness checks using MLR (treated-as-continuous) yielded substantively identical conclusions (see §4).

Fit criteria. We report CFI/TLI (≥ 0.90/0.95), RMSEA (≤ 0.06–0.08; 90% CI), and SRMR (≤ 0.08) [13]. Reliability/Validity. We report Cronbach's α, Composite Reliability (CR), Average Variance Extracted (AVE) for convergent validity, and HTMT/HTMT2 for discriminant validity [13], [14]. Structural specifications. Paths were SQ → IQ, SQ → II, IQ → II, II → OI, with direct links SQ → OI and IQ → OI to test mediation. Indirect effects were obtained via bias-corrected bootstrapping (B = 5,000). Moderation and invariance. Infrastructure reliability (self-reported connectivity and electricity stability) moderated quality → II via observed interaction terms (e.g., SQ × Connectivity → II), probed at ±1 SD using simple-slope plots. Multi-group checks (students vs. faculty; Kassala vs. Gedaref) assessed configural/metric/scalar invariance using WLSMV DIFFTEST with ΔCFI ≤ 0.01 as the decision rule prior to cross-group comparisons [13]. Common-method bias controls. Procedural remedies (anonymity, proximal item separation, varied anchors) were implemented a priori. Post-hoc checks using a latent method factor/marker variable indicated negligible method variance (ΔCFI < .005).

3.6.1 Measurement results (for coherence with §4)

CFA fit: CFI = 0.951, TLI = 0.944, RMSEA = 0.046 (90% CI: 0.041–0.051), SRMR = 0.041. Reliability/Convergence (Table 2): all α ≥ 0.93, CR ≥ 0.94, AVE ≥ 0.60. Discriminant validity (Table 3): all HTMT ≤ 0.83; the maximum was HTMT(II, OI) = 0.83 < 0.85 [14].

Table 2 — Reliability and convergent validity (observed values)

Construct	**Items**	**α**	**CR**	**AVE**
SQ	9	0.94	0.95	0.63
IQ	9	0.93	0.94	0.60
II	9	0.95	0.96	0.69
OI	9	0.96	0.96	0.71

Table 3 — Discriminant validity (HTMT)

	SQ	**IQ**	**II**	**OI**
SQ	—	0.79	0.66	0.58
IQ		—	0.73	0.62

II			—	0.83
OI				—

3.6.2 Structural model (paths, mediation, moderation)

SEM fit: CFI = 0.949, TLI = 0.942, RMSEA = 0.047 (90% CI: 0.042–0.052), SRMR = 0.044. Direct paths: SQ→IQ=0.72 (p<.001); IQ→II=0.55 (p<.001); SQ→II=0.21 (p=.004); II→OI=0.75 (p<.001); SQ→OI=0.06 (p=.18 ns); IQ→OI=0.04 (p=.27 ns). Indirects: SQ→II→OI=0.16 [0.10,0.23] (p<.001); IQ→II→OI=0.41 [0.32,0.51] (p<.001) — consistent with full/semi-full mediation [6], [13]. Moderation: Connectivity×SQ→II β=0.18 (p=.011; Δ=+0.22, p=.006); Connectivity×IQ→II β=0.14 (p=.028); Electricity×SQ→II β=0.12 (p=.039); Electricity×IQ→II p=.12 (ns). Multi-group invariance: configural acceptable; metric ΔCFI=0.002; scalar ΔCFI=0.006; II→OI slightly stronger in Kassala than Gedaref (Δβ=0.07, p=.046).

3.7 Tabular Reporting

Table 4 — Model fit indices (CFA & SEM)

Model	χ^2(df)	CFI	TLI	RMSEA [90% CI]	SRMR
Measurement (CFA)	1120.5 (588)	0.951	0.944	0.046 [0.041–0.051]	0.041
Structural (SEM)	1187.3 (593)	0.949	0.942	0.047 [0.042–0.052]	0.044

Table 5 — Hypotheses, tests, and observed outcomes

Code	Hypothesis	Test	Observed β (p)	Supported?
H1	SQ → IQ (+)	Standardized path	0.72 (< .001)	Yes
H2	IQ → II (+)	Standardized path	0.55 (< .001)	Yes
H3	SQ → II (+)	Standardized path	0.21 (.004)	Yes
H4	II → OI (+)	Standardized path	0.75 (< .001)	Yes
H5a	SQ → OI (direct)	Standardized path	0.06 (.18)	No
H5b	IQ → OI (direct)	Standardized path	0.04 (.27)	No
H5c	SQ → II → OI	Indirect (B = 5,000)	0.16 (< .001)	Yes
H5d	IQ → II → OI	Indirect (B = 5,000)	0.41 (< .001)	Yes

H6a	Connectivity × SQ → II	Interaction	0.18 (.011)	Yes
H6b	Connectivity × IQ → II	Interaction	0.14 (.028)	Yes
H6c	Electricity × SQ → II	Interaction	0.12 (.039)	Yes
H6d	Electricity × IQ → II	Interaction	0.07 (.12)	No

4. Results

4.1 Sample Profile

The analytic sample comprised N = 412 respondents: Students 78% (n = 321) and Faculty 22% (n = 91). By institution: Kassala 52% (n = 214) and Gedaref 48% (n = 198). Table 6 summarizes the distribution.

Table 6 — Sample characteristics

Characteristic	Category	n	%
Role	Students	321	78
	Faculty	91	22
University	Kassala	214	52
	Gedaref	198	48

Note. Percentages are column-wise and sum to ~100%.

4.2 Measurement Model

Model fit for the CFA was strong: CFI = 0.951, TLI = 0.944, RMSEA = 0.046 (90% CI: 0.041–0.051), SRMR = 0.041. Reliability and convergent validity were adequate across constructs (α ≥ 0.93, CR ≥ 0.94, AVE ≥ 0.60). Discriminant validity held with HTMT ≤ 0.83 (max HTMT(II, OI) = 0.83), satisfying contemporary SEM expectations for ordered-indicator models [13], [14]. These results replicate the methodological summary in §3.6.1; see Tables 2–4 for the full indices. Conclusion: The measurement model supports proceeding to structural testing.

4.3 Structural Model (Direct Effects)

The SEM achieved good fit: CFI = 0.949, TLI = 0.942, RMSEA = 0.047 (90% CI: 0.042–0.052), SRMR = 0.044. Standardized direct paths are reported in Table 7.

Table 7 — Standardized direct paths (SEM)

Path	β	p	Interpretation
SQ → IQ	0.72	< .001	Strong, positive
IQ → II	0.55	< .001	Moderate, positive
SQ → II	0.21	.004	Small-to-moderate, positive
II → OI	0.75	< .001	Large, positive
SQ → OI	0.06	.18	n.s. (direct)
IQ → OI	0.04	.27	n.s. (direct)

Inference. Quality (SQ, IQ) → II; II → OI. Non-significant direct links support mediation tests [6], [13].

4.4 Indirect Effects (Mediation via II)

Bias-corrected bootstrapping (B = 5,000) indicated substantial, significant indirect effects via II (Table 8).

Table 8 — Indirect effects (via II)

Indirect path	Effect	95% CI	p	Conclusion
SQ → II → OI	0.16	[0.10, 0.23]	< .001	Supported
IQ → II → OI	0.41	[0.32, 0.51]	< .001	Supported

Synthesis. Quality translates to OI primarily via II.

4.5 Moderation by Infrastructure Reliability

Connectivity and electricity reliability strengthened quality→II pathways (Table 9). Interactions were positive and significant for Connectivity × (SQ, IQ) and for Electricity × SQ; the Electricity × IQ interaction was non-significant, although simple slopes remained positive at both reliability levels.

Table 9 — Moderation results and simple slopes (±1 SD)

Moderator	Interaction	β_int	p	Simple slope (Low)	p	Simple slope (High)	p	Δ (High–Low)
Connectivity × SQ → II	SQ×Conn	0.18	.011	0.10	.090	0.32	< .001	+0.22
Connectivity × IQ → II	IQ×Conn	0.14	.028	0.49	< .001	0.61	< .001	+0.12

Electricity × SQ → II	SQ×Elec	0.12	.039	0.15	.024	0.27	< .001	+0.12
Electricity × IQ → II	IQ×Elec	—	.12	0.52	< .001	0.58	< .001	+0.06 (n.s.)

Notes. β_int is the standardized interaction; simple slopes at ±1 SD; n.s. = non-significant interaction.

4.6 Multi-Group Invariance and Group Differences

Configural, metric, and scalar invariance held across role (students vs. faculty) and university (Kassala vs. Gedaref) using WLSMV DIFFTEST and the ΔCFI ≤ 0.01 rule [13], supporting valid cross-group comparisons. A small, meaningful difference emerged: II → OI was marginally stronger in Kassala than Gedaref (Δβ = 0.07, p = .046).

Table 10 — Invariance summary (WLSMV)

Split	Level	ΔCFI	Decision
Role (Students vs. Faculty)	Configural → Metric	0.002	Invariant
	Metric → Scalar	0.006	Invariant
University (Kassala vs. Gedaref)	Configural → Metric	0.003	Invariant
	Metric → Scalar	0.007	Invariant

Note. DIFFTEST results and ΔCFI jointly supported invariance at each step.

4.7 Robustness Checks

Treating indicators as continuous with MLR reproduced the same pattern of significance and similar magnitudes for key paths; conclusions are therefore not estimator-dependent [15], [16].

5. Discussion

5.1 Principal findings

This study shows that e-learning creates institutional value primarily via individual gains. Quality elevates Individual Impact (II), and II— in turn—strongly drives Organizational Impact (OI) (β_{II→OI} = 0.75, *p* < .001), whereas direct quality→OI paths are non-significant (Table 7). Indirect effects are substantial—0.16 for SQ→II→OI and 0.41 for IQ→II→OI—supporting a full/semi-full mediation pattern consistent with the IS-Impact logic that separates "quality" from realized "impacts" [6], [13]. Infrastructure reliability amplifies quality→II links—especially connectivity (Δ slope = +0.22, *p* = .006)—indicating that the same level of platform quality yields larger educational returns when uptime and network stability are safeguarded (Table 9). Together, these results position II as the principal conduit from technical/content quality to organizational value.

5.2 Comparison with prior work

Our pathway structure aligns with the IS-Impact tradition that positions quality as a precursor to impacts rather than an outcome itself [6]. Recent e-learning applications using PLS-SEM/IPMA similarly report strong quality→individual pathways with institutional value emerging indirectly [7]. Systematic reviews in African and low-resource higher education underscore that infrastructure and institutional support act as gatekeepers of effectiveness—precisely the moderators tested here [8]–[10]. On the delivery side, evidence for offline/low-bandwidth patterns (e.g., micro-servers, mobile-first, asynchronous content) complements our moderation results by demonstrating practical routes to stabilize connectivity/latency in the field [17]–[20]. Our contribution is to jointly test mediation and infrastructure moderation in a single model under conflict-affected, bandwidth-constrained circumstances, with invariance across role and university (Table 10), thereby strengthening generalizability.

5.3 Practical implications (KPIs and levers)

Findings translate into actionable levers with trackable KPIs:

- Prioritize Information Quality (IQ). Its indirect effect on OI is large (0.41 via II). Focus on relevance, completeness, timeliness, clarity in content pipelines (editorial checklists, release cadence) [6], [13].
  KPI: ≥ 90% of course pages pass a content-quality checklist each term; median page-update age ≤ 30 days.

- Safeguard System Quality (SQ) under low bandwidth. SQ still matters (β = 0.21 to II; 0.16 indirect to OI). Emphasize mobile usability, response time, error-free ops [6], [17]–[20].
  KPIs: median mobile page-load ≤ 2.5 s on 3G; uptime ≥ 97% in term time; crash rate ≤ 0.5% per session.

- Engineer for reliability (moderation insight). Because connectivity reliability magnifies quality→II, invest in caching, offline micro-servers (e.g., Raspberry-Pi Moodle nodes), scheduled sync, and backup power [17], [18].
  KPIs: ≥ 80% of required assets cachable offline; scheduled-sync success ≥ 95%; mean time to recover from outage ≤ 30 min.

- Reduce data-heavy synchronous use. Video conferencing is data-intensive; prefer asynchronous/lightweight formats and short micro-videos with compressed assets where synchronous activity is unavoidable [19], [20]. Policy: cap live sessions to essentials; require downloadable alternatives.

- Institutional coordination (explaining Kassala > Gedaref on II→OI). The slightly stronger II→OI in Kassala ($\Delta\beta$ = 0.07) suggests tighter academic–IT coordination and programmatic follow-through may help convert learner gains into organizational outcomes—worth emulation via shared governance and performance dashboards.

5.4 Theoretical implications

Results reinforce IS-Impact's quality→impact separation [6], showing that organizational outcomes materialize through the individual level. Moderation by infrastructure clarifies boundary conditions in low-resource contexts—often asserted but rarely modeled explicitly [8]–[10]. Strong measurement (α/CR/AVE; HTMT ≤ 0.83) and WLSMV for ordinal indicators align with best-practice SEM reporting [13]–[16], lending credibility to both the measurement and structural inferences.

5.5 Robustness and strengths

Conclusions are robust to estimator choice (MLR checks), hold across roles and institutions (invariance with ΔCFI ≤ 0.01), and rely on a validated 36-indicator instrument with excellent reliability and convergence (Tables 2–4). Overall model fit (CFA/SEM CFI ≈ 0.95; RMSEA ≈ 0.046–0.047) supports the specified structure.

5.6 Limitations

A cross-sectional design limits causal claims; self-reports may introduce common-method bias despite procedural/post-hoc safeguards [13]. The setting covers two universities in Sudan; external validity beyond similar low-resource contexts must be argued by analogy. We did not explicitly model Service Quality as distinct from IS-Impact's broader quality domains—future extensions could reintroduce it when theoretically warranted. Finally, objective usage logs (latency, error rates, bandwidth consumed) were not integrated into the SEM—adding them would triangulate perceived with observed quality.

5.7 Future work

We recommend quasi-experimental rollouts that manipulate content pipelines (to raise IQ) and reliability interventions (offline caching, micro-servers, backup power), tracking changes in II and OI. Incorporate LMS/server telemetry and cost-effectiveness analyses of offline-first strategies [17], [18]. Multi-site replications across additional Sudanese or regional universities—and longitudinal panels—can test durability and scale.

6. Conclusions and Recommendations

6.1 Conclusion

The findings indicate that institutional value in e-learning is generated primarily through the individual level (II). Both Information Quality (IQ) and System Quality (SQ) enhance II, and II strongly drives Organizational Impact (OI) ($\beta_{II\rightarrow OI} = 0.75$, $p < .001$), while direct quality→OI paths are non-significant. Indirect effects are large—0.16 for SQ→II→OI and 0.41 for IQ→II→OI—consistent with a full/semi-full mediation pattern. Moderation results further show that connectivity and electricity reliability amplify the quality→II pathways (simple-slope difference under stable connectivity $\Delta = +0.22$, $p = .006$). Measurement invariance across roles and institutions supports valid comparisons and strengthens generalizability to similar low-resource settings. Overall, the conclusions align with the IS-Impact logic and contemporary SEM standards [6], [13], and they are coherent with evidence on mobile-first/offline delivery in bandwidth-constrained environments [17]–[20].

6.2 Operational Recommendations (KPIs and Implementation Tracks)

(A) Raise Information Quality (IQ).
Establish a course editorial pipeline (checklists for relevance, completeness, timeliness, clarity).
KPI: ≥ 90% of course pages pass the content-quality checklist each term; median page update age ≤ 30 days. [6], [13]

(B) Improve System Quality (SQ) for low bandwidth and mobile.
Emphasize mobile usability, reduced response time, and fewer errors/crashes.
KPIs: mobile page-load on 3G ≤ 2.5 s; operational uptime ≥ 97% during term; crash rate ≤ 0.5% per session. [6], [17]–[20]

(C) Engineer reliability (leverage moderation).
Deploy offline micro-servers (e.g., Raspberry-Pi Moodle nodes), enable caching, schedule synchronization, and provide basic power backup.
KPIs: ≥ 80% of core materials accessible offline; sync success rate ≥ 95%; mean time to recovery after outage ≤ 30 min. [17], [18]

(D) Policy for synchronous use.
Reduce reliance on data-intensive video meetings; offer compressed asynchronous alternatives.
Policy: limit live sessions to essential activities and provide downloadable substitutes. [19], [20]

(E) Governance and dashboards.
Create a unified performance dashboard aggregating the KPIs above, reviewed weekly by academic leadership and IT.
Ownership: Colleges/Faculties + E-Learning Deanship + IT Deanship.

(F) Capacity building and communication.
Train faculty on low-data content design and publish performance proofs (load time, error rates).
Conduct student outreach on effective asynchronous study and mobile data management.

6.3 Execution Roadmap (12 Months)

Table 11 — Roadmap and KPIs (four-quarter rollout)

Track	Action	KPI	Target	Responsible unit	Timeline
IQ	Stand up course editorial line + QA checklists	% pages meeting QA	≥ 90%/term	E-Learning Deanship + Departments	Q1–Q2
SQ	Improve mobile/latency/errors	Mobile 3G load time	≤ 2.5 s	IT + Platform vendor	Q1–Q3
Reliability	Deploy micro-servers / caching / scheduled sync	% offline-ready materials	≥ 80%	IT	Q2–Q3
Reliability	Basic power backup (labs/servers)	MTTR	≤ 30 min	IT + Facilities	Q2
Teaching policy	Synchronous-use policy + alternatives	% courses compliant	100%	Academic Affairs	Q1
Governance	KPI dashboard and weekly reviews	Regular reports	1/week	Senior leadership + implementers	Q1–Q4

Note. MTTR = mean time to recovery.

6.4 Risks and Mitigation

Table 12 — Key risks and mitigation actions

Risk	Impact	Likelihood	Mitigation
Prolonged power outages	Access/sync disruption	High	Local backup power, recovery playbooks, night-time sync windows
Network congestion/weak links	Higher load times	High	Offline caching, asset compression, local course mirrors
Change resistance	Slow policy uptake	Medium	Training & incentives, KPI transparency, responsive tech support

Departmental content burden	Delayed updates	Medium	Editorial templates, publishing cadence, lightweight staged reviews

6.5 Closing

This work indicates that quality + reliability are the decisive levers for converting e-learning in low-resource environments into measurable institutional value. Prioritizing IQ first—paired with targeted SQ enhancements and stabilization of connectivity/power—should yield larger individual gains that, per the observed pathways, translate into tangible organizational outcomes. The proposed roadmap and KPIs provide Kassala and Gedaref Universities with a practical path for implementation and continuous monitoring, with clear potential to scale across other Sudanese and regional institutions.

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