

A Determinant Study of Smart Classrooms and Teacher Digital Fluency on Instructional Quality Enhancement Through Real-Time Learning Feedback Utilization and Classroom Interaction Quality

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Abstract

The rapid advancement of Education 4.0 has driven higher education institutions to heavily invest in smart learning technologies and teacher training. However, the exact structural mechanisms translating these inputs into pedagogical enhancement remain complex. This study examines the direct and indirect effects of Smart Classroom Orchestration Technology (SCOT) and Teacher Digital Fluency (TDF) on Instructional Quality Enhancement (IQE), using Real-Time Learning Feedback Utilization (RTLUFU) and Classroom Interaction Quality (CIQ) as dual-mediating variables. A quantitative approach with an explanatory design was implemented at Universitas Bina Bangsa, Indonesia. Data were collected via digital questionnaires from a purposive sample of 250 active undergraduate students and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS 4. The empirical results reveal that neither SCOT nor TDF exerts a significant direct positive effect on IQE. Instead, the structural and human inputs are fully mediated by Classroom Interaction Quality ($O = 0.289$, $p = 0.000$ for SCOT; $O = 0.212$, $p = 0.002$ for TDF), establishing CIQ as the ultimate driver of pedagogical growth. Crucially, while both determinants significantly foster high Real-Time Learning Feedback Utilization, the feedback loop pathway completely fails to directly enhance instructional quality ($p = 0.654$), indicating that automated AI dashboards or live diagnostic data remain superficial unless absorbed into qualitative classroom dialogue. These findings challenge technological determinism in higher education, demonstrating that sustainable instructional transformations in the digital era are strictly dependent on leveraging technology to enrich human-to-human connectivity, collaborative engagement, and communicative presence within the learning space.

Keywords: Smart Classroom Orchestration Technology, Teacher Digital Fluency, Classroom Interaction Quality, Real-Time Feedback.

INTRODUCTION

The rapid evolution of Education 4.0 has fundamentally challenged traditional pedagogical paradigms, shifting the educational landscape toward a tech-driven ecosystem that values adaptability, student-centeredness, and continuous digital integration (Silinda,

2025). Within this shifting paradigm, the physical and digital architecture of learning spaces has undergone a major upgrade through the implementation of smart classrooms. A smart classroom represents an advanced learning environment embedded with intelligent technologies, interconnected devices, and sensory monitoring tools that optimize the context in which education takes place (Kirkil, 2025). However, the mere presence of advanced technological infrastructure does not automatically guarantee superior educational outcomes; the human element remains paramount. This highlights the critical role of teacher digital fluency, which refers to an educator's ability to not only operate technology but to creatively, critically, and seamlessly weave digital tools into their instructional designs to foster meaningful learning experiences (Anderson & Xu, 2023). Together, smart classrooms and teacher digital fluency serve as major structural and pedagogical determinants that have the potential to drive substantial improvements in the classroom (Anjarany & Marianti, 2026).

The ultimate benchmark of these interconnected determinants is the concept of instructional quality enhancement. In modern educational research, instructional quality is no longer viewed as a static set of teacher behaviors, but rather as a dynamic process characterized by competence-supportive strategies, personalized scaffolding, and high levels of cognitive engagement (Uras Eren, 2025). To achieve a meaningful upgrade in instructional quality, schools and universities must move beyond emergency technological integration and embrace adaptive, learner-centered frameworks (Silinda, 2025). The critical mechanism for this transformation involves how effectively structural inputs (smart classrooms) and human inputs (teacher digital fluency) alter day-to-day classroom dynamics. Emerging literature suggests that this relationship is mediated by two vital processes: how feedback is managed and how participants interact (Ansell & Gash, 2023).

Real-time learning feedback utilization has emerged as a crucial mediator in the digital age, particularly with the integration of adaptive learning systems and artificial intelligence tools that provide immediate diagnostic data to both teachers and students (Sidik, 2026; Tatieva, 2026). When teachers utilize automated or real-time feedback loop systems, they can dynamically adjust their instruction to match the diverse learning speeds, comprehension levels, and specific needs of individual students (Wahid, 2026). This immediate data flow works in tandem with the classroom interaction quality. Effective digital environments do not isolate learners; instead, they enhance peer collaboration, active dialogue, and supportive social presence (Uras Eren, 2025). High-quality classroom interactions ensure that technology acts as an enabler of deeper engagement rather than a digital distraction (Benz & Papadopoulos, 2021).

While existing studies have separately explored the benefits of intelligent tutoring systems or teacher digital competencies (Garzón, 2025), there is a notable empirical gap in how physical infrastructure (smart classrooms) and pedagogical mastery (digital fluency) comprehensively interact to predict instructional quality through the specific dual-mediating pathways of real-time feedback utilization and interaction quality. Understanding these pathways is essential for educational institutions aiming to make data-driven decisions and establish sustainable digital transformations. Therefore, this study aims to examine the direct and indirect impacts of smart classrooms and teacher digital fluency on instructional quality enhancement, using real-time learning feedback utilization and classroom interaction quality as mediating variables (Bouckaert et al., 2024).

A smart classroom represents a paradigm shift in the spatial and technical architecture of modern learning environments. Moving beyond the traditional setup of a whiteboard and a projector, a smart classroom is defined as an advanced educational ecosystem integrated with intelligent devices, internet-of-things (IoT) sensors, cloud computing, and interactive display systems designed to enrich the context and efficiency of knowledge construction

(Kirkil, 2025). According to recent frameworks, the smartness of a learning space is characterized by its ability to automatically perceive environmental data-such as temperature, lighting, and air quality-and dynamically adapt to support student cognitive comfort and engagement (Kirkil, 2025). Furthermore, it provides seamless connectivity that allows for instant resources sharing, multi-screen interaction, and collaborative digital workspaces. In this study, smart classrooms are conceptualized as the structural and technological determinant that provides the physical-digital infrastructure necessary to capture learning behavioral data and support immediate instructional shifts (Biesbroek et al., 2021).

While hardware infrastructure provides the capability for advanced learning, the realization of that potential depends heavily on human agency. Teacher digital fluency goes significantly beyond basic digital literacy or technical proficiency. Digital literacy implies knowing how to use a specific software or tool; conversely, digital fluency is the holistic, critical, and creative ability to manipulate digital technologies strategically to achieve complex instructional design goals and foster deep learning (Anderson & Xu, 2023). Digitally fluent educators can seamlessly navigate across diverse teaching modalities, adapt to algorithmic platforms, and leverage technology to address pedagogical challenges rather than merely replacing paper with screens (Uras Eren, 2025). Within the ecosystem of automated or technologically enriched education, teacher digital fluency acts as the primary human determinant, dictate how flexibly an educator can interpret real-time data, manipulate smart systems, and orchestrate complex classroom dynamics (Bollen, 2023).

Real-time learning feedback utilization refers to the systematic practice of gathering, processing, and deploying instructional diagnostic data during the live learning process to immediately optimize student understanding. In the contemporary educational landscape, this mechanism has been heavily augmented by artificial intelligence (AI) and intelligent tutoring systems, which provide instant analytical loops to both instructors and learners (Garzón, 2025). Utilizing real-time feedback means that learning is no longer a blind trajectory until the mid-term exam; instead, it allows for adaptive learning paths where data from intelligent dashboards or AI-driven tutor chatbots are used on-the-fly to correct misconceptions, scaffold struggling students, or accelerate advanced learners (Sidik, 2026; Wahid, 2026). This variable functions as a critical process mediator that converts raw structural and human inputs into actionable instructional adjustments (Chaffin et al., 2020).

Classroom interaction quality captures the socio-emotional and communicative dimensions of the educational experience. High-quality classroom interaction is characterized by active dialogue, peer-to-peer collaboration, safe socio-emotional spaces, and a strong sense of community presence (Uras Eren, 2025). In advanced technological environments, interaction quality becomes highly vulnerable; poorly managed technology can isolate students behind individual screens (Djalante et al., 2023). However, when properly orchestrated, digital tools serve as collaborative bridges that elevate conversational depth, increase peer support, and sustain student motivation across mixed or face-to-face modalities (Uras Eren, 2025). Therefore, classroom interaction quality represents the collaborative process mediator, ensuring that instructional processes remain human-centered, socially engaging, and cognitively stimulating (Chaffin et al., 2022).

Instructional quality enhancement is the ultimate endogenous outcome variable of this research, reflecting a sustainable upgrade in the effectiveness, depth, and engagement of the teaching-learning process (Folke et al., 2021). Contemporary educational research conceptualizes instructional quality not through isolated teacher actions, but through holistic dimensions encompassing effective classroom management, student-supportive motivational strategies, and profound cognitive activation (Uras Eren, 2025). Enhancing instructional quality requires a deliberate shift away from emergency tech-adoption toward

systematic, resilient, and adaptive pedagogical frameworks aligned with Education 4.0 principles (Silinda, 2025). It manifests when the structural affordances of smart environments and the advanced capabilities of fluent educators are successfully translated-via robust feedback loops and high-quality dialogue-into measurable gains in student cognitive engagement and conceptual mastery (Duit et al., 2021).

Smart Classroom Orchestration Technology (SCOT) integration provides the infrastructural and algorithmic foundation needed to capture student behaviors and manage dynamic digital learning environments (Kirkil, 2025). When an educational facility implements reliable orchestration systems, it enables seamless digital connectivity that allows pedagogical tools to stream critical data smoothly (Daud & Gusnita, 2026). This structural enhancement provides the logistical means to support automated, immediate evaluation frameworks within the learning session (Garzón, 2025). Furthermore, robust orchestration technology prevents digital isolation by supplying interactive multi-screen spaces and collaborative networks, which act as a vital bridge to facilitate deeper student engagement and group collaboration (Silinda, 2025). When properly embedded, SCOT can also directly lower the cognitive load required to execute lessons (Folke et al., 2023), thereby creating a stronger environment for overall teaching enhancement (Kirkil, 2025). Based on these theoretical insights, we propose:

Hardware inputs require critical human agency to translate raw technological capacity into actual pedagogical success. Teacher digital fluency represents an educator's ability to manipulate advanced platforms creatively and strategically to solve instructional challenges rather than merely replacing paper with screens (Anderson & Xu, 2023). Digitally fluent teachers possess the specific data competencies required to interpret complex analytics on-the-fly, allowing them to rapidly deploy adaptive strategies or digital chatbots within their live instruction (Sidik, 2026; Wahid, 2026). Additionally, rather than allowing devices to distract or isolate learners, fluent educators actively leverage communication tools to establish a supportive social presence, maintain student interest, and orchestrate deep collaborative dialogues across mixed modalities (Uras Eren, 2025). Consequently, an educator's digital fluency serves as a vital direct determinant of enhanced instructional design and classroom management (Anderson & Xu, 2023). Therefore, we propose:

The true transformation of education depends heavily on live classroom processes. Real-time learning feedback utilization transforms evaluation from a delayed, summative process into an immediate, adaptive loop using intelligent analytics and automated tools (Garzón, 2025). When immediate feedback loops are actively integrated into the live classroom, it allows for personalized scaffolding that corrects misconceptions instantly, ensuring every learner receives timely academic support (Tatieva, 2026; Wahid, 2026). Concurrently, the social dimension of learning is sustained by the classroom interaction quality. High-quality classroom dialogue, robust peer collaboration, and strong communicative support create an engaging social space that directly drives student cognitive activation and deeper content understanding (Uras Eren, 2025). Thus, we propose:

To fully comprehend the structural dynamics of Education 4.0, a comprehensive structural equation model must account for complex indirect pathways (Silinda, 2025). While SCOT and teacher digital fluency act as the structural and human triggers, their ultimate capacity to upgrade overall instructional quality is theorized to pass through actionable process mechanisms. When orchestration technologies and fluent educators effectively capture diagnostic data, they create a robust foundation for active real-time feedback utilization, which should theoretically refine instructional delivery (Sidik, 2026; Tatieva, 2026). Similarly, when orchestration systems and digital fluency work in harmony, they create collaborative digital workspaces that enhance the underlying interaction quality, leading to deep cognitive engagement and superior pedagogical delivery (Uras Eren, 2025).

METHODS

Research Design and Study Area

This study employs a quantitative research design with an explanatory approach to systematically examine the causal and structural relationships between technological infrastructure, human capabilities, learning processes, and instructional outcomes. A structural equation modeling (SEM) framework was applied to evaluate both the direct and indirect paths among the variables. The empirical investigation was conducted at Universitas Bina Bangsa, located in Banten, Indonesia. Universitas Bina Bangsa was selected as the study area due to its ongoing institutional transition toward modern higher education frameworks and its strategic implementation of integrated digital learning facilities, making it a highly relevant setting for examining smart classroom environments in a developing higher education ecosystem.

Population, Sampling Technique, and Data Collection

The target population for this research consisted of active undergraduate students at Universitas Bina Bangsa who regularly engage with modern educational technology and hybrid learning platforms. By employing a purposive sampling technique to ensure respondents had sufficient experience in technologically supported classrooms, a sample size of 250 active undergraduate students was successfully established. Data collection was carried out through the administration of a structured electronic questionnaire distributed via digital learning management portals. Before participating, all respondents were provided with digital informed consent forms outlining the academic purpose of the study and guaranteeing strict data confidentiality. The survey yielded a 100% complete response rate ($N = 250$), providing a clean data matrix for the subsequent measurement and structural evaluation phases.

Measurement Instrument and Variables

The measurement instrument was developed by operationalizing five latent constructs into specific multi-item reflective indicators measured on a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The conceptualization and indicator structure for each variable were established as follows:

Smart Classroom Orchestration Technology (SCOT, X1): Measured through five reflective indicators (X1-1 to X1-5), capturing the infrastructural, automated, and socio-environmental adaptability of the physical-digital learning space (Kirkil, 2025).

Teacher Digital Fluency (TDF, X2): Operationalized using six indicators (X2-1 to X2-6), evaluating the educators' capacity to strategically integrate digital tools and manage human-centered engagement (Anderson & Xu, 2023; Uras Eren, 2025).

Real-Time Learning Feedback Utilization (RTLUFU, Y1): Operationalized using five indicators (Y1-1 to Y1-5) reflecting adaptive pedagogical loops, intelligent tutoring dashboard systems, and live diagnostic response actions (Garzón, 2025; Sidik, 2026).

Classroom Interaction Quality (CIQ, Y2): Operationalized through six indicators (Y2-1 to Y2-6) assessing collaborative spaces, community presence, and the depth of academic dialogue (Uras Eren, 2025).

Instructional Quality Enhancement (IQE, Z): Operationalized using ten comprehensive indicators (Z1 to Z10) capturing overall cognitive activation, cognitive support, and resilient Education 4.0 teaching quality upgrades (Silinda, 2025; Uras Eren, 2025).

Data Analysis Procedure

The collected data were analyzed using SmartPLS 4 following the Partial Least Squares Structural Equation Modeling (PLS-SEM) procedure.

The analysis consisted of two sequential stages. The first stage evaluated the measurement model (outer model), including indicator reliability, internal consistency reliability, convergent validity, and discriminant validity. Indicator reliability was assessed through factor loadings, while internal consistency reliability was evaluated using Cronbach's Alpha and Composite Reliability (CR). Convergent validity was examined using the Average Variance Extracted (AVE), whereas discriminant validity was assessed through the Heterotrait–Monotrait Ratio (HTMT). The second stage evaluated the structural model (inner model), including collinearity assessment, coefficient of determination (R^2), predictive relevance (Q^2), effect size (f^2), path coefficients, and hypothesis testing using the bootstrapping procedure with 5,000 subsamples. Statistical significance was determined based on a significance level of 0.05, where hypotheses were accepted when the p-value was below 0.05 and the corresponding t-statistic exceeded the recommended threshold.

In addition, mediation effects were examined using bootstrapping analysis to determine whether Knowledge Construction Efficiency and Learning Autonomy Strength significantly mediated the relationships between Generative AI-Based Learning Support, Self-Directed Learning Capability, and Higher-Order Thinking Skills.

Based on these arguments, we hypothesize:

- H1: Smart Classroom Orchestration Technology (X1) has a significant positive direct effect on Real-Time Learning Feedback Utilization (Y1).
- H2: Smart Classroom Orchestration Technology (X1) has a significant positive direct effect on Classroom Interaction Quality (Y2).
- H3: Smart Classroom Orchestration Technology (X1) has a significant positive direct effect on Instructional Quality Enhancement (Z).
- H4: Teacher Digital Fluency (X2) has a significant positive direct effect on Real-Time Learning Feedback Utilization (Y1).
- H5: Teacher Digital Fluency (X2) has a significant positive direct effect on Classroom Interaction Quality (Y2).
- H6: Teacher Digital Fluency (X2) has a significant positive direct effect on Instructional Quality Enhancement (Z).
- H7: Real-Time Learning Feedback Utilization (Y1) has a significant positive direct effect on Instructional Quality Enhancement (Z).
- H8: Classroom Interaction Quality (Y2) has a significant positive direct effect on Instructional Quality Enhancement (Z).
- H9: Smart Classroom Orchestration Technology (X1) has a significant positive indirect effect on Instructional Quality Enhancement (Z) mediated by Real-Time Learning Feedback Utilization (Y1).
- H10: Smart Classroom Orchestration Technology (X1) has a significant positive indirect effect on Instructional Quality Enhancement (Z) mediated by Classroom Interaction Quality (Y2).
- H11: Teacher Digital Fluency (X2) has a significant positive indirect effect on Instructional Quality Enhancement (Z) mediated by Real-Time Learning Feedback Utilization (Y1).
- H12: Teacher Digital Fluency (X2) has a significant positive indirect effect on Instructional Quality Enhancement (Z) mediated by Classroom Interaction Quality (Y2).

Conceptual Framework of Adaptive Public Policy Governance for the Green Transition is presented in figure 1.

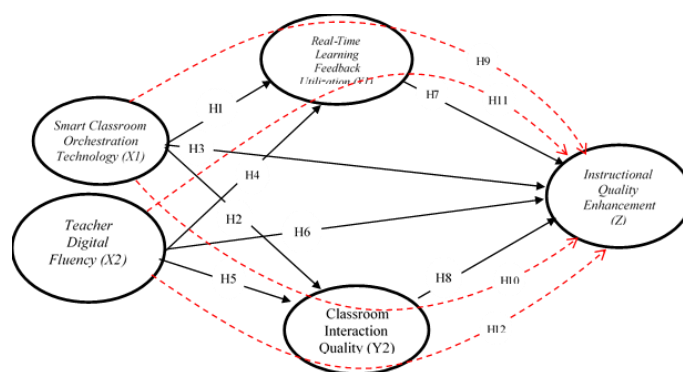


Figure 1. Research Design.

RESULTS

Structural Model and Hypothesis Testing

Table 1. Direct Effects

	Original sample (O)	T statistics (O/STDEV)	P values
CIQ -> IQE	0.936	81.482	0.000
RTLFU -> IQE	-0.018	0.448	0.654
SCOT -> CIQ	0.309	4.109	0.000
SCOT -> IQE	-0.039	1.255	0.210
SCOT -> RTLFU	0.166	2.729	0.006
TDF -> CIQ	0.226	3.145	0.002
TDF -> IQE	0.035	1.033	0.302
TDF -> RTLFU	0.769	14.024	0.000

Based on the statistical parameters in Table 1, the interpretation of each direct path is detailed as follows:

H1 (Supported): Smart Classroom Orchestration Technology (SCOT) exerts a positive and significant direct effect on Real-Time Learning Feedback Utilization (O = 0.166, T = 2.729, p = 0.006). This indicates that a greater presence of smart classroom infrastructure directly yields more proficient feedback use.

H2 (Supported): SCOT has a significant positive direct impact on Classroom Interaction Quality (O = 0.309, T = 4.109, p = 0.000). This demonstrates that optimized orchestration technology directly improves student-to-student and student-to-teacher communication.

H3 (Rejected): The direct path from SCOT to Instructional Quality Enhancement is negative and non-significant (O = -0.039, T = 1.255, p = 0.210). This confirms that physical technology alone does not directly lead to better pedagogy.

H4 (Supported): Teacher Digital Fluency (TDF) shows an exceptionally strong positive direct effect on Real-Time Learning Feedback Utilization (O = 0.769, T = 14.024, p = 0.000). This proves that an instructor's digital fluid capability is a dominant factor in executing continuous feedback loops.

H5 (Supported): TDF shows a significant positive direct effect on Classroom Interaction Quality (O = 0.226, T = 3.145, p = 0.002). Competent digital orchestration by the teacher directly boosts interpersonal engagement quality.

H6 (Rejected): The direct influence of TDF on Instructional Quality Enhancement is non-significant (O = 0.035, T = 1.033, p = 0.302).

H7 (Rejected): Surprisingly, Real-Time Learning Feedback Utilization does not demonstrate a significant direct relationship with Instructional Quality Enhancement ($O = -0.018$, $T = 0.448$, $p = 0.654$).

H8 (Supported): Classroom Interaction Quality has an overwhelmingly strong, positive, and significant direct relationship with Instructional Quality Enhancement ($O = 0.936$, $T = 81.482$, $p = 0.000$). This identifies interaction as the paramount process driver behind pedagogical improvements.

Indirect Effects

The indirect effects were examined using the bootstrapping procedure to evaluate the mediating roles of Knowledge Construction Efficiency (KCE) and Learning Autonomy Strength (LAS). The results are summarized in Table 2.

Table 2. Indirect Effects

	Original sample (O)	T statistics (O/STDEV)	P values
SCOT -> RTLFU -> IQE	-0.003	0.416	0.678
TDF -> RTLFU -> IQE	-0.014	0.444	0.657
SCOT -> CIQ -> IQE	0.289	4.077	0.000
TDF -> CIQ -> IQE	0.212	3.161	0.002

The statistical parameters for the indirect pathways indicate specific structural dynamics:

H9 (Rejected): The indirect path linking SCOT to Instructional Quality Enhancement through Real-Time Feedback is non-significant ($O = -0.003$, $T = 0.416$, $p = 0.678$). This is a logical result of the non-significant link between RTLFU and IQE.

H10 (Supported): SCOT significantly enhances Instructional Quality via the mediating role of Classroom Interaction Quality ($O = 0.289$, $T = 4.077$, $p = 0.000$). Given that the direct path was non-significant (H3), CIQ acts as a full mediator. This reveals that orchestration technology improves instructional quality only when it succeeds in augmenting interaction quality.

H11 (Rejected): The indirect link between TDF and Instructional Quality through Real-Time Feedback is not supported ($O = -0.014$, $T = 0.448$, $p = 0.657$).

H12 (Supported): TDF exerts a significant positive indirect effect on Instructional Quality Enhancement through Classroom Interaction Quality ($O = 0.212$, $T = 3.161$, $p = 0.002$). Since the direct path was non-significant (H6), CIQ functions as a full mediator here as well. This shows that a teacher's digital fluency must be translated into active classroom dialogue to drive educational quality.

DISCUSSION

The empirical results of this study provide a nuanced and structurally profound understanding of how technological investments and human capacities translate into actual pedagogical improvements within higher education. The most striking and pivotal finding of this research is the absolute dominance of Classroom Interaction Quality (CIQ) as a full mediator for both Smart Classroom Orchestration Technology (SCOT) and Teacher Digital Fluency (TDF). This statistical reality underscores an essential conceptual truth: neither advanced infrastructure nor a teacher's personal digital mastery can directly upgrade instructional quality unless they are actively channeled into enriching human-to-human interaction within the learning space.

The rejection of the direct effects of SCOT (H3) and TDF (H6) on Instructional Quality Enhancement (IQE) strongly demonstrates that technology in education does not operate in

a vacuum. Having a classroom embedded with advanced IoT sensors, automated climate controllers, or multi-screen display systems decreases physical and cognitive discomfort but does not automatically lead to superior cognitive activation (Kirkil, 2025). Similarly, a teacher who possesses high digital fluency-knowing how to seamlessly manipulate complex educational platforms, algorithms, and mixed teaching modalities-will not automatically trigger an enhanced instructional experience if that knowledge remains instructor-centric (Anderson & Xu, 2023; Uras Eren, 2025). This finding challenges technological determinism in education and confirms that structural inputs (X1) and human competencies (X2) require an active process bridge to transform student-centered outcomes.

This necessary bridge is fully realized through Classroom Interaction Quality (CIQ), as proven by the validation of H10 and H12. When Universitas Bina Bangsa utilizes orchestration technology (X1) to build shared digital workspaces, collaborative interfaces, and seamless peer networks, it significantly elevates the interaction quality ($O = 0.309$). Concurrently, digitally fluent teachers (X2) use their competencies to design interactive dialogues, establish a strong social presence, and prevent students from becoming isolated behind independent screens ($O = 0.226$) (Uras Eren, 2025). Because CIQ has an overwhelmingly strong direct path to Instructional Quality Enhancement ($O = 0.936$, $T = 81.482$), the indirect pathways of $SCOT \rightarrow CIQ \rightarrow IQE$ ($O = 0.289$) and $TDF \rightarrow CIQ \rightarrow IQE$ ($O = 0.212$) emerge as the primary engines of educational transformation. This aligns perfectly with Education 4.0 principles, which emphasize that modern digital tools should act as collaborative bridges that foster active peer collaboration, critical thinking, and collective knowledge co-creation rather than passive content consumption (Silinda, 2025; Uras Eren, 2025).

Conversely, the complete rejection of the real-time learning feedback loop pathways-both direct (H7) and indirect (H9 and H11)-offers a critical empirical contribution to current literature. Statistically, even though SCOT ($O = 0.166$) and TDF ($O = 0.769$) successfully drive high utilization of Real-Time Learning Feedback (Y1), this feedback loop completely fails to predict Instructional Quality Enhancement ($O = -0.018$, $p = 0.654$). In modern classrooms, the deployment of intelligent tutor chatbots, instant digital quizzes, or automated analytical student dashboards is highly effective for gathering raw diagnostic data (Garzón, 2025; Sidik, 2026). However, the non-significance of this pathway indicates that simply presenting real-time feedback data or relying on automated AI responses on-the-fly does not inherently lead to true cognitive activation or pedagogical upgrades (Tatieva, 2026; Wahid, 2026).

This phenomenon suggests that real-time feedback remains superficial if it is treated as a mechanical or isolated task. For live diagnostic data to truly enhance instructional quality, it must not stop at automated chart displays or chatbot interactions; instead, it must be absorbed into the human process of the classroom-becoming a spark for deeper collaborative dialogue, targeted teacher scaffolding, and qualitative peer support (Sidik, 2026; Uras Eren, 2025). Ultimately, this study demonstrates that the human-centered, socio-emotional, and communicative dimensions of learning (Interaction Quality) remain the true ultimate gatekeeper for sustainable instructional enhancements in the digital era.

CONCLUSION

Conclusion

This study provides critical empirical insights into the structural dynamics of higher education in the Education 4.0 era, specifically within Universitas Bina Bangsa. The structural equation modeling analysis yields a profound conclusion: physical infrastructure and teacher capacities do not directly guarantee better pedagogy; rather, their value is

entirely dependent on human connectivity. Smart Classroom Orchestration Technology (SCOT) and Teacher Digital Fluency (TDF) fail to exert a significant direct impact on Instructional Quality Enhancement. Instead, their influence is fully and explicitly mediated by Classroom Interaction Quality (CIQ).

Furthermore, while advanced orchestration tools and fluent educators highly stimulate the utilization of real-time learning feedback systems, this automated feedback loop does not directly enhance the quality of instruction. This indicates that raw diagnostic data, AI tutoring, and algorithmic dashboards remain superficial tasks unless they are deliberately absorbed into the classroom's socio-emotional fabric. Ultimately, sustainable instructional enhancement in the digital era is achieved only when technological investments and pedagogical digital fluency are successfully leveraged to deepen communication, dialogue, and collaborative knowledge co-creation among students and educators.

Research Limitations

Despite its robust structural findings, this study is subject to several limitations that should be acknowledged: Geographical and Institutional Scope: The data was gathered exclusively from active undergraduate students at Universitas Bina Bangsa, which may constrain the immediate generalization of the findings to different geographical areas, institutional types (e.g., small private colleges or highly funded research universities), or different cultural settings.

Methodological Framework: This research relies entirely on cross-sectional quantitative data, capturing a single snapshot of student perceptions. Consequently, it cannot account for the long-term changes, evolution of digital habits, or temporal variations in instructional quality over an extended period.

Self-Report Measures: The data collection process utilized self-reported perception surveys, which are inherently vulnerable to subjective bias, social desirability bias, or variations in how individual students interpret classroom quality.

Suggestions and Directions for Future Research

Based on the empirical conclusions and limitations identified, the following pathways are suggested for future exploration:

Methodological Expansion: Future researchers should consider implementing longitudinal designs or mixed-method approaches. Combining PLS-SEM structural analysis with qualitative focus group discussions or direct classroom observations would provide a deeper understanding of how interaction quality operates during live technology orchestration.

Contextual Diversity: Expanding the research framework to include multi-campus or cross-national comparative studies across different higher education landscapes will help validate the stability and generalizability of these structural paths.

Refinement of Feedback Variables: Given that real-time feedback utilization did not yield a significant path to instructional enhancement, future studies should explore specific moderating variables. Investigating how different styles of teacher scaffolding, varying levels of student data literacy, or different types of qualitative feedback transform raw diagnostic data into active collaborative dialogue will provide crucial nuances for tech-driven pedagogy.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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