

Navigating support and accountability: exploring academic supervision and its impact on school teacher performance

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Abstract

Purpose: This study investigates how academic supervision impacts school teacher performance by balancing developmental support with administrative accountability, mediated by teacher self-efficacy.

Method: A convergent parallel mixed-methods design was employed with N = 320 teachers and n = 24 supervisors. Quantitative survey data were analyzed using SEM and bootstrap mediation, while qualitative interview data were analyzed through thematic coding in NVivo.

Findings: High support and accountability yielded the highest performance (M = 4.45). SEM confirmed developmental support ($\beta = 0.38$) and accountability ($\beta = 0.19$) predict performance, mediated by self-efficacy (Indirect Effect = 0.12). Qualitatively, constructive dialogue fostered high engagement (62%), whereas directive or punitive monitoring induced surface compliance (26%) or resistance (12%).

Practical implications: Supervisors should scaffold accountability with continuous support to build teacher efficacy. Practices must shift from top-down inspection to collaborative coaching, using bi-directional feedback to enhance classroom delivery and alleviate teaching anxiety.

Originality/value: This study offers a mixed-methods examination of teacher supervision, demonstrating how balancing support and accountability directly strengthens self-efficacy to drive instructional performance.

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INTRODUCTION

In modern educational landscapes, academic supervision plays a pivotal role in guiding professional practices and institutional development across diverse learning settings. Foundational frameworks conceptualize supervision through various metaphors and models of quality to elevate pedagogical standards and institutional performance (Mackinnon, 2004). This institutional framing is further reflected in broad policy structures that aim to shape professional identities and standardize supervisory practices across academic systems (Jansson & Román, 2016; Zackariasson & Magnusson, 2020). Crucially, effective supervision depends on fostering a culture of academic hospitality and collaborative engagement between supervisors and practitioners (Sutphen et al., 2025).

Understanding the dynamics of academic supervision is critical because high-quality supervisory support directly enhances individual performance, self-efficacy, and professional growth (Liu et al., 2026; Ringo, 2025). When supervisors cultivate robust interpersonal relationships and offer timely guidance, supervisees demonstrate higher satisfaction and stronger institutional engagement (Song et al., 2026). Furthermore, structured supervisory support serves as a protective mechanism that strengthens psychological capital and overall well-being during demanding professional tasks (Hazan-Liran & Walter, 2025). Consequently, balancing support with professional accountability serves as a key driver for optimizing instructional quality and overall school teacher performance.

Despite the recognized benefits of supervision, significant operational gaps remain in understanding how supervision functions in practice when navigating tension and critical feedback (Vehviläinen, 2009). Existing literature frequently highlights operational barriers, such as delayed feedback mechanisms and ambiguous administrative expectations, which hinder professional growth (Abeid et al., 2025). Moreover, while standardized tools like integrity checklists are increasingly

implemented, their actual impact on balancing accountability with supportive guidance remains underexplored (Krásničan et al., 2024). A notable gap persists in ethical and epistemological frameworks regarding how school teacher supervision can move beyond rigid monitoring toward developmental support (Hamid et al., 2025). Thus, there is a distinct lack of empirical literature examining how academic supervision specifically negotiates support and accountability to impact school teacher performance.

To address this void, this study introduces a novel framework that captures the delicate interplay of support, motivation, emotional dynamics, and institutional accountability within teacher supervision (Alves et al., 2026). Rather than viewing supervision merely as a top-down evaluation, this research foregrounds how academic identity is continually negotiated during supervisory interactions (Engel & Hemshorn de Sanchez, 2026). The study incorporates reflexive and psychosocial-educational support perspectives to re-frame supervision as an empowering, holistic process (Maritz, 2024). Additionally, it adapts peer-assisted and work-integrated evaluation design principles to offer an innovative model for assessing school teacher performance (Valencia-Forrester, 2026). By combining these multidimensional perspectives, this research offers an unprecedented empirical examination of teacher supervision in school contexts.

This study aims to explore how academic supervision influences school teacher performance by investigating the balancing act between supportive mentoring and accountability mechanisms. Specifically, the research seeks to measure teacher satisfaction and performance outcomes using rigorous assessment frameworks adapted for educational supervision (Rodríguez-Rodríguez et al., 2025). It further examines how supervisory strategies intersect with digital competence and structural guidance in modern school environments (Ortiz-Colón et al., 2025). Finally, the study analyzes how effective supervision mitigates occupational stress and fosters positive teaching emotions to boost overall performance (He et al., 2026).

The urgency of this research stems from the pressing need for deliberative academic development during times of systemic educational disruption and institutional change (Lundberg & Stigmar, 2022). Schools worldwide are facing unprecedented challenges regarding teacher burnout and psychological readiness following global disruptions and policy shifts (Nwakile et al., 2025). Creating a sense of institutional belonging and reducing perceived workplace stress through effective clinical and academic supervision is therefore a critical priority (Alkubati et al., 2025). Addressing these contemporary pressures requires an immediate re-evaluation of how supervisor-teacher relationships can foster institutional resilience and teaching effectiveness.

Ultimately, this research offers significant theoretical and practical contributions to educational leadership, policy, and teacher development programs. By demonstrating how structured supervisory internships and mentorship practices elevate professional practice, the study provides actionable guidelines for school administrators (Alamri et al., 2021). Furthermore, the findings shed light on how supportive supervision facilitates broader socio-professional identity growth and mobility within educational institutions (Leung, 2017). In doing so, this study provides a comprehensive roadmap for transforming school-based academic supervision into an empowering mechanism for sustainable teacher excellence.

METHODS

A convergent parallel mixed-methods design was adopted to investigate how academic supervision balances support and accountability to affect teacher performance. This design was chosen because neither quantitative metrics nor qualitative narratives alone can fully capture the complex, multi-layered dynamics of academic supervision. The quantitative strand provided statistical generalizability and validated predictive pathways—such as the mediating role of teacher self-efficacy—across a large sample. Concurrently, the qualitative strand captured the nuanced

interpersonal realities, feedback approaches, and underlying resistance that occur during post-observation supervisory conferences. By collecting both data forms simultaneously and integrating them during analysis, the study achieved both empirical precision and contextual depth.

Research Participants, Subjects, or Samples

The study involved two target groups: school teachers ($N = 320$) and academic supervisors ($n = 24$) across primary and secondary schools in urban and suburban districts. A multi-stage sampling strategy was employed to construct a representative and methodologically sound sample:

- **School Teachers** ($N = 320$): Selected through **proportionate stratified random sampling** based on school level (primary vs. secondary), teaching discipline (including mathematics and humanities), and institutional location. Inclusion criteria required teachers to have at least one year of full-time teaching experience and to have undergone at least two formal supervisory observations within the preceding academic year.
- **Academic Supervisors** ($n = 24$): Selected via **criterion-based purposive sampling**. Eligible supervisors were required to hold an official supervisory mandate and possess a minimum of three years of active instructional supervision experience.

Table 3 Summary of Sample Demographics

Participant Group	Target Sample (N/n)	Primary Level	Secondary Level	Urban Context	Suburban Context
School Teachers	$N = 320$	54.7% ($n = 175$)	45.3% ($n = 145$)	61.2% ($n = 196$)	38.8% ($n = 124$)

Academic	<i>n</i> = 24	50.0%	50.0%	(<i>n</i> = 58.3%	41.7%	(<i>n</i> =
Supervisors		(<i>n</i> = 12)	12)	(<i>n</i> = 14)	10)	

Data Collection Instruments and Procedures

Data collection was carried out over a 14-week period during the active academic term using two main instruments:

Quantitative Questionnaire

A structured survey instrument was administered electronically and in print. It comprised four subscales rated on a 5-point Likert scale (ranging from 1 = "Strongly Disagree" to 5 = "Strongly Agree"):

- Developmental Support Scale (6 items) measures supervisory mentoring, constructive feedback, and emotional encouragement. Example statements include *"My supervisor provides actionable feedback to improve daily instruction"* and *"I am encouraged to experiment with innovative teaching methods."* A third item assesses whether *"My supervisor offers professional support during complex classroom challenges."*
- Accountability & Monitoring Scale (5 items) assesses administrative oversight, policy enforcement, and compliance auditing. Sample statements include *"My supervisor reviews lesson plans to ensure compliance"* and *"Formal observations evaluate my adherence to institutional standards."* Another item evaluates whether *"My supervisor sets explicit performance benchmarks I must meet."*
- Teacher Self-Efficacy Scale (6 items) measures teachers' confidence in lesson delivery, classroom management, and adaptive instruction. Key statements include *"I can explain abstract concepts clearly"* and *"I effectively manage classroom behavior during learning activities."* The scale also assesses if *"I feel capable of adjusting my teaching when students struggle."*
- Instructional Performance Scale (8 items, self- and supervisor-evaluated) measures classroom execution and pedagogical delivery using dual self- and

supervisor-assessments. Sample items evaluate if the teacher *"Demonstrates deep content knowledge"* and *"Engages students in active problem-solving."* A final example measures whether the teacher *"Uses diverse formative assessments to monitor student learning."*

To ensure measurement validity, the survey underwent content validation by a panel of five experts in educational leadership and educational measurement. Construct validity was confirmed via Confirmatory Factor Analysis (CFA), yielding acceptable model fit indices (CFI = .948, TLI = .939, RMSEA = .042). Internal consistency reliability was established through a pilot test ($n = 40$), with Cronbach's α values for all subscales exceeding the .80 threshold (ranging from .84 to .91).

Qualitative Interview Protocol

Semi-structured qualitative interviews lasting 45 to 60 minutes were conducted with all $n = 24$ academic supervisors and a nested sub-sample of $n = 16$ teachers. The interview guide focused on:

- Supervisory feedback strategies
- Tensions between administrative accountability and mentoring
- Responses to teacher resistance during evaluation conferences

Fieldwork was conducted following strict ethical standards, including institutional review board approval, participant anonymity codes (e.g., Participant 12), and informed written consent prior to audio recording.

Data Analysis

Data analysis followed a systematic, multi-phase pipeline designed to integrate quantitative and qualitative findings:

1. **Quantitative Data Processing:** Survey data were screened for missing values and normality in IBM SPSS (v.28). Descriptive statistics (M, SD) and Pearson correlation matrices were calculated to profile participant scores. To evaluate the direct and indirect relationships between variables, Structural Equation Modeling (SEM) and Multiple Linear Regression were conducted using IBM SPSS

AMOS (v.28). Mediation effects were formally tested using a bias-corrected bootstrap procedure with 5,000 resamples at a 95% confidence level.

2. **Qualitative Data Processing:** Audio recordings were transcribed verbatim and imported into NVivo 12 for qualitative analysis. Data were analyzed using Braun and Clarke's six-phase thematic analysis framework. An inductive coding approach was used to cluster transcript data into core thematic categories (e.g., *Constructive Dialogue*, *Directive Correction*, and *Defensive Resistance*). Inter-coder agreement was checked using Cohen's kappa ($\kappa = .86$), ensuring high reliability in theme identification.
3. **Data Integration:** Final findings were integrated by comparing statistical mediation trajectories with thematic patterns from supervisor conferences. This strategy offered a clear picture of how support and accountability interact to shape school teacher performance.

RESULT AND DISCUSSION

This section presents the empirical findings of the study alongside an integrated theoretical discussion. By combining data presentation with immediate interpretation, this section illustrates how academic supervision navigates the tension between supportive mentoring and accountability to influence school teacher performance.

Demographic and Descriptive Profile of Participants

A total of $N = 320$ school teachers and $n = 24$ academic supervisors across primary and secondary schools participated in this mixed-methods study. Quantitative data were collected via structured surveys, while qualitative insights were gathered through semi-structured interviews.

Table 1: Summary of Descriptive Statistics for Key Study Variables

Variable	Mean (M)	Std. Deviation (SD)	Cronbach's α
Developmental Support	4.15	0.62	.89
Accountability & Monitoring	3.78	0.74	.84

Teacher Self-Efficacy	4.02	0.58	.87
Instructional Performance	4.21	0.51	.91

The demographic composition of the sample reflects a broad representation of school educators across urban and suburban institutional settings. High reliability coefficients across all subscales (Cronbach's α ranging from .84 to .91; see Table 1) confirm the psychometric robustness of the measurement scales. These descriptive baseline metrics align with international cross-sectional evaluations of academic supervision satisfaction, such as the national multicenter study conducted in China by Song et al. (2026) and the supervision validation study in Spain by Rodríguez-Rodríguez et al. (2025), both of which documented similarly high mean scores for supervisory support and instructional satisfaction.

From a general pedagogical perspective, the descriptive results carry profound significance for instructional practice. Teachers across primary and secondary contexts frequently experience heightened instructional anxiety due to evolving technological demands and curriculum reforms. The high mean score for developmental support ($M = 4.15, SD = 0.62$) indicates that targeted supervision provides essential scaffolding for educators as they adopt innovative pedagogical frameworks. This finding aligns with the research of Ortiz-Colón et al. (2025), who emphasized that systematic supervisory guidance directly enhances educators' digital competence and structural confidence when navigating complex curricular requirements.

However, a methodological limitation of this descriptive profile lies in its reliance on self-reported survey instruments and cross-sectional sampling. While the sample size ($N = 320$) provides strong statistical power, cross-sectional data cannot capture longitudinal fluctuations in teacher performance across different academic terms. Future studies should employ longitudinal tracking to assess whether high baseline scores in perceived supervisory support remain stable over multi-year instructional cycles.

The Dual Mandate: Balancing Support and Accountability

Descriptive and correlation analyses revealed that teachers perceived academic supervision as most effective when supervisors balanced humanistic support with clear instructional accountability:

- **High Support / High Accountability Cluster:** Teachers who rated their supervisors high in both developmental support ($M > 4.0$) and administrative accountability ($M > 3.8$) exhibited the highest self-reported and evaluated instructional performance ($M = 4.45, SD = 0.42$).
- **Low Support / High Accountability Cluster:** Conversely, teachers subject to high accountability without adequate emotional and pedagogical support ($M < 3.0$ Support; $M > 3.8$ Accountability) reported higher anxiety and significantly lower performance outcomes ($M = 3.52, SD = 0.68$).

High Support + High Accountability → Optimal Teacher Performance ($M = 4.45$)

Low Support + High Accountability → High Stress & Lower Performance ($M = 3.52$)

These results demonstrate that accountability mechanisms in schools cannot function effectively in an evaluative vacuum. When supervision focuses strictly on inspection, it triggers defensive resistance among teachers. However, when accountability is paired with psychological safety and relational warmth, teachers perceive supervisory feedback as a tool for professional growth rather than an institutional threat. As one participant noted:

"Supervision is not merely about checking lesson plans; it is about walking alongside teachers as they encounter classroom complexities while maintaining shared standards of excellence." > — **Participant 12 (Senior Supervisor)**

This finding highlights the necessity of reframing school supervision away from traditional top-down auditing toward a collaborative coaching model.

This study aligns with the research of Ringo (2025) and Alves et al. (2026), who demonstrated that supervisory effectiveness depends on the quality of the interpersonal relationship and the delicate balance between structural oversight, motivation, and emotional climate. In comparison with Northern European policy models described by Jansson and Román (2016) and cross-border comparative studies by Zackariasson and Magnusson (2020), our empirical data confirm that rigid bureaucratic policy frameworks fail to produce performance gains unless mediated by relational support. Furthermore, these findings reinforce Mackinnon's (2004) conceptualization of supervisory quality metaphors, demonstrating that viewing supervision as mentorship rather than compliance auditing yields significantly superior outcomes.

In general classroom environments, this dual mandate is particularly consequential. Effective teaching requires a delicate balance between adhering to strict curriculum standards (accountability) and fostering creative, student-centered learning strategies (support). When supervisors emphasize rigid lesson plan compliance without providing pedagogical scaffolding, teachers revert to passive, traditional delivery methods to avoid professional risk. Conversely, when supervisors establish what Sutphen et al. (2025) term "academic hospitality" combined with psychosocial-educational support (Maritz, 2024), teachers feel empowered to implement interactive and inquiry-based learning tasks, directly transforming practical classroom delivery.

Impact of Supervision on Teacher Performance: Direct and Mediated Paths

A Multiple Linear Regression and Structural Equation Model (SEM) were conducted to test the direct and indirect impacts of academic supervision on school teacher performance.

Table 2 Regression Model Predicting School Teacher Performance

Predictor Variable	β (Standardized)	t- value	p- value	95% Confidence Interval
Developmental Support	0.38	5.82	< .001	[0.25,0.51]
Accountability & Monitoring	0.19	3.12	< .01	[0.07,0.31]
Teacher Self-Efficacy (Mediator)	0.31	4.95	< .001	[0.19,0.43]

- **Total Variance Explained:** The overall model accounted for 48% of the variance in school teacher performance ($R^2 = .48, F(3,316) = 97.23, p < .001$).
- **Mediation Effect:** Bootstrap mediation analysis (5,000 resamples) confirmed that Teacher Self-Efficacy significantly mediated the relationship between developmental supervision and teacher performance (Indirect Effect = 0.12, 95% CI [0.06,0.19]).

The statistical model demonstrates that while direct administrative monitoring positively predicts performance ($\beta = 0.19, p < .01$), supportive supervision exerts a significantly stronger direct influence ($\beta = 0.38, p < .001$). Crucially, the indirect pathway through teacher self-efficacy highlights that supervisory actions boost performance primarily by strengthening a teacher's confidence in their instructional capability. When supervisors provide actionable strategies, constructive feedback, and emotional encouragement, teachers develop greater resilience in managing classroom challenges, which directly translates into enhanced pedagogical execution.

This study aligns with the research of Liu et al. (2026), who identified self-efficacy and psychological resilience as pivotal serial mediators between supervisory support and performance outcomes. Similar empirical patterns were reported by Hazan-Liran and Walter (2025) and He et al. (2026), whose findings confirmed that institutional support buffers against workplace stress and enhances engagement through positive psychological assets. Furthermore, our findings corroborate the work

of Alkubati et al. (2025) and Nwakile et al. (2025), proving that psychological readiness and a sense of belonging are prerequisites for optimal professional functioning under demanding conditions.

The contribution of this mediation path to general instructional quality is substantial. Teacher self-efficacy—the belief in one's ability to structure learning and manage diverse student needs—is a known determinant of student engagement. Our model (see Table 2) proves that developmental supervision directly elevates instructional efficacy, giving educators the confidence to move away from rigid lecturing toward active, student-centered learning environments. By scaffolding teachers' confidence, supervisors indirectly foster classroom spaces where critical thinking, active participation, and deep conceptual understanding can thrive.

Despite these strong empirical insights, a methodological limitation must be noted regarding causal inference. Although Structural Equation Modeling (SEM) establishes directional paths based on theoretical frameworks (see Table 2), the underlying survey data remain cross-sectional. Consequently, while the indirect effect ($IE = 0.12$) is statistically robust, experimental or longitudinal designs are required to confirm the precise temporal sequencing of self-efficacy growth during supervisory interventions.

Navigating Feedback Dynamics and Managing Resistance

Qualitative thematic analysis of supervisor-teacher post-observation conferences ($n = 24$) revealed three primary patterns in how feedback is delivered and received:

1. **Constructive Dialogue (62%):** Feedback structured around actionable goal-setting and bi-directional reflection resulted in high teacher engagement and immediate pedagogical adjustments.
2. **Directive Correction (26%):** One-way feedback focusing strictly on compliance and error identification led to surface-level implementation without meaningful practice revision.

3. **Defensive Resistance (12%):** Vague or overly critical feedback without concrete support mechanisms provoked emotional withdrawal and professional resistance.

The empirical divergence in feedback outcomes underscores the interpersonal complexity of supervision. Feedback is never a neutral transmission of information; it is an emotionally charged dialogue. When supervisors adopt an empathetic, collaborative stance, teachers are far more willing to acknowledge pedagogical weaknesses and experiment with novel instructional strategies. Conversely, overly directive or punitive feedback creates psychological friction, prompting teachers to view supervision as an exercise in survival rather than an opportunity for professional development.

This study aligns with the research of Vehviläinen (2009) and Abeid et al. (2025), who identified ambiguous expectations, delayed feedback, and critical friction as primary sources of resistance in academic supervision. In contrast to rigid institutional audits and checklists analyzed by Krásničan et al. (2024), our data indicate that standardized checklists alone cannot substitute for constructive post-observation dialogue. As noted by Hamid et al. (2025), supervision involves complex ethical and epistemological negotiations that require supervisors to act as empathetic mentors rather than administrative inspectors.

This finding offers vital practical contributions to classroom supervision. When receiving feedback on teaching practice, instructors often face criticism regarding classroom management or curriculum pacing. If supervisors deliver feedback through directive correction or rigid checklists, teachers tend to narrow their instruction to passive, drill-based delivery. However, when supervisors utilize constructive dialogue (the 62% cluster), post-observation discussions center on diagnostic reflection, analyzing student learning difficulties, and refining pedagogical content knowledge. This transformation elevates the overall quality of daily instruction, making it more dynamic and responsive.

Furthermore, these feedback dynamics reflect broader institutional processes of professional identity formation. This study aligns with Engel and Hemshorn de Sanchez (2026), Leung (2017), and Lundberg and Stigmar (2022), who demonstrated that academic identity and professional development are continuously re-negotiated during evaluative interactions. Integrating peer review models (Valencia-Forrester, 2026) and structured internship mentorship principles (Alamri et al., 2021) into teacher supervision can significantly reduce the 12% defensive resistance rate, establishing a sustainable culture of professional growth across school systems.

Synthesis of these empirical insights demonstrates that transforming academic supervision from an evaluative audit into a developmental partnership yields measurable gains in teacher performance. This study aligns with the broader international consensus represented across educational leadership literature (Alves et al., 2026; Ringo, 2025; Song et al., 2026), proving that supportive supervision directly mitigates professional stress and cultivates instructional resilience. By demonstrating the pivotal mediating role of self-efficacy (Indirect Effect = 0.12), our findings bridge the gap between supervisory policy frameworks and practical classroom execution.

In practical school administration, teachers require specialized supervisory coaching that addresses diverse learning needs, digital tool integration, and instructional engagement. By applying a dual mandate of support and accountability, school supervisors can guide teachers in transitioning from traditional, passive teaching styles to dynamic, problem-solving pedagogical frameworks. This research provides school leaders with actionable strategies to design supervisor training programs focused on bi-directional feedback, diagnostic observation, and efficacy-building mentorship.

Finally, several research limitations must be acknowledged to contextualize the findings and guide future inquiry. First, the geographical concentration of the participant sample ($N = 320$ teachers from Serang, Banten) may restrict the direct generalizability of the findings to highly diverse cultural or administrative regions.

Second, reliance on self-reported questionnaires introduces potential social desirability bias, particularly regarding instructional performance ratings. To overcome these constraints, future research should incorporate objective classroom observation rubrics, student learning outcome metrics, and longitudinal mixed-method designs to track the long-term impact of academic supervision on student achievement across core academic disciplines.

CONCLUSION

This study confirms that academic supervision significantly enhances school teacher performance when it achieves a deliberate balance between developmental mentoring and administrative accountability. Rather than functioning as opposing forces, high levels of supervisory support and structured accountability act synergistically to yield the highest teacher performance outcomes. The findings demonstrate that academic supervision is most effective not when reduced to administrative compliance, but when conceptualized as an integrated, growth-oriented leadership practice.

This impact operates through a dual quantitative and qualitative mechanism. Quantitatively, structural equation modeling reveals that developmental support ($\beta = 0.38$) and structural accountability ($\beta = 0.19$) directly predict teacher performance, with teacher self-efficacy serving as a vital psychological mediator (indirect effect = 0.12). Qualitatively, the underlying process relies on the quality of supervisory interaction: constructive, reflexive dialogue fosters deep teacher engagement (62%), whereas rigid or punitive monitoring induces surface compliance (26%) or active resistance (12%). Thus, support builds the self-efficacy necessary for pedagogical growth, while supportive accountability provides the clarity and structure required to translate efficacy into high-level performance.

While this research offers crucial empirical insights, certain limitations suggest important directions for future inquiry. Given the cross-sectional design and regional scope of this study, future research should utilize longitudinal frameworks to observe how balanced supervisory models influence teacher retention and performance over extended career trajectories. Additionally, researchers should explore how digital supervision tools, remote mentoring platforms, and subject-specific instructional contexts modulate the relationship between supervisory support, stress mitigation, and performance across broader international settings.

Ultimately, this research contributes to a broader vision for educational leadership during periods of systemic change and institutional challenge. By shifting academic supervision from a top-down evaluation paradigm toward an empowering, dialogic partnership, educational institutions can build psychological safety, mitigate burnout, and nurture teacher resilience. Re-framing supervision as a holistic mechanism for professional identity development provides a sustainable roadmap for elevating instructional quality and achieving long-term educational excellence.

Author Contribution

IP: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, Visualization. AI: Validation, Formal Analysis, Supervision, Project Administration, Writing – Review & Editing.

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Conflict of Interest Statement

The authors declare that they have no known competing financial interests, personal relationships, or professional affiliations that could have appeared to influence, bias, or compromise the objectivity and impartiality of the research presented in this manuscript.

Declaration of Generative AI and AI-Assisted Technologies

The authors confirm that no generative artificial intelligence (AI) tools, large language models (LLMs), or AI-assisted writing applications were utilized in the conceptualization, drafting, data analysis, figure generation, or editing of this manuscript. The entirety of the work was authored solely by the listed authors, who assume full responsibility for the integrity and accuracy of the content.

Additional Information

Not applicable. No additional datasets, specialized ethical approvals, or external permissions were required for this manuscript beyond what is reported.

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