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Examining the mediating role of professional development in the relationship between artificial intelligence utilization and teacher performance

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ABSTRACT

This study investigates the relationships among AI utilization, professional development, and teacher performance in learning contexts. A total of 100 teachers from preschool to high school in the Greater Blitar region, Indonesia, participated. Data were collected using a cross-sectional survey and analyzed via PLS-SEM to examine direct and indirect relationships. Quantitative results served as the primary source, followed by qualitative interviews to provide deeper contextual insights and interpret the quantitative findings. Results show that AI utilization is positively associated with professional development, which is also positively associated with teacher performance. Furthermore, AI utilization demonstrates an indirect relationship with teacher performance through professional development, while no significant direct relationship between AI utilization and teacher performance was identified. Findings highlight the potential mediating role of professional development in explaining how AI utilization may be associated with effective teaching practices.

Keywords: artificial intelligence, mixed methods, professional development, PLS-SEM, teacher performance

INTRODUCTION

The rapid development of Artificial Intelligence (AI) has brought about significant transformations in various sectors, including education. AI technology is increasingly being utilized to support the learning process through adaptive learning systems (Kabudi et al., 2021; Strielkowski et al., 2025), learning analytics (Ouyang et al., 2023), and automated assessment (Seneviratne & Manathunga, 2025), enabling teachers to improve the effectiveness of instruction and create more personalized, efficient (Vorobyeva et al., 2025), and data-driven learning experiences (Sajja et al., 2025). Accordingly, AI is recognized not only as a technological tool but also as a strategic means to foster pedagogical innovation and enhance teaching practices in educational settings (Holmes & Tuomi, 2022; Zawacki-Richter et al., 2019). However, the successful integration of AI depends not only on the availability of technology but also on teachers' ability to understand and effectively apply it within their pedagogical practice. As the primary agents of technology integration, teachers play a crucial role in aligning AI with instructional strategies that address students' learning needs. Consequently, teacher professional development becomes essential to ensure that AI contributes meaningfully to improvements in teaching quality and performance rather than functioning merely as a technical innovation without substantial classroom impact (Holmes & Tuomi, 2022; Tan et al., 2025b).

Despite the growing adoption of Artificial Intelligence (AI) in education, its impact on teacher performance remains theoretically underdeveloped and empirically inconsistent. Previous studies suggest that AI has the potential to enhance instructional practices and improve teaching effectiveness; however, these benefits are largely indirect and depend on teachers' competencies, readiness, and professional capacity to integrate AI into their instructional practices (Tan et al., 2025a; Zawacki-Richter et al., 2019). Recent evidence further indicates that AI utilization alone does not necessarily lead to improved teacher performance, as its effectiveness is determined by how teachers meaningfully internalize and apply AI within pedagogical contexts (Liu et al., 2026; Ning et al., 2024). These finding imply that AI should be viewed not as a direct determinant of teacher performance but as a resource whose educational value depends on complementary teacher-related capabilities, highlighting the need to identify the underlying mechanisms through which AI contributes to effective teaching.A critical limitation in the existing literature is the tendency to examine AI utilization, teacher competence, and performance in isolation, without adequately explaining the underlying mechanism that connects these constructs. In particular, the mediating role of professional development has received limited empirical attention, despite being theoretically essential in transforming technological inputs into instructional outcomes (Duan & Zhao, 2024; Holmes & Tuomi, 2022). Furthermore, current professional development practices are often fragmented and insufficiently aligned with AI integration, leading to a gap between teachers' technological skills and their pedagogical application (Hava & Babayiğit, 2025; Yue et al., 2024). Consequently, there is a lack of a comprehensive, process-oriented model that explains how AI utilization influences teacher performance through professional development. Addressing this gap is crucial for advancing theoretical understanding and ensuring that AI adoption in education leads to meaningful improvements in teaching effectiveness.

Several previous studies have made important contributions to elucidating the role of artificial intelligence (AI) in education, particularly in enhancing teacher professional development and performance. Liu et al. (2026) demonstrated that AI-based professional development positively correlates with teachers' confidence in AI and encourages AI integration into the learning process, thus improving not only technical skills but also teacher readiness to adopt technology. Furthermore, Duan and Zhao (2024) found that AI-based technology interventions can enhance teachers' professional growth, strengthen their teaching independence, and help reduce the workload and stress associated with using technology in learning. Furthermore, Tan et al. (2025a) revealed that teachers' AI competence positively influences their teaching practices, which in turn support teaching performance, demonstrating the importance of integrating technology, pedagogy, and content in learning. These findings are supported by Ning et al. (2024) who stated that integrated knowledge, particularly that which combines aspects of technology, pedagogy, and content, is a key factor in the successful implementation of AI in the classroom and in improving learning effectiveness.

In practice, teacher competency development still tends to separate pedagogical training from mastery of AI-based technology. According to Celik et al. (2022), the integration of AI into learning cannot be achieved solely through mastery of technical aspects, as technological knowledge must be combined with pedagogical knowledge to effectively support the learning process. However, Hava and Babayiğit (2025) point out that the implementation of AI in schools is still often introduced as a technological innovation without being accompanied by the development of aligned pedagogical competencies and content knowledge. This situation indicates that the development of teachers' AI competencies has not yet been fully carried out in an integrated manner. In line with these findings, Ning et al. (2024) explain that teachers' AI competencies are developed through interconnected knowledge components that support AI-based teaching practices. As a result, teachers may possess the technical skills to operate AI systems but may not yet be able to apply them effectively in instruction, or conversely, they may have strong pedagogical competencies but lack the adequate ability to utilize AI meaningfully in instructional practice (Celik et al., 2022; Ning et al., 2024).

Accordingly, the primary objective of this study is to examine the mediating role of professional development in the relationship between AI utilization and teacher performance, thereby providing a clearer theoretical explanation of how technological adoption can be translated into improved instructional outcomes. In addition, this study offers a methodological contribution by employing a mixed-methods approach, which constitutes a significant novelty within the current literature on AI in education. Quantitative analysis is used to identify structural relationships among AI utilization, professional development, and teacher performance, while qualitative exploration provides deeper insights into teachers' experiences, challenges, and pedagogical adaptation processes in implementing AI-based practices. The integration of both approaches enables a more comprehensive understanding of the phenomenon, allowing the study not only to explain statistical relationships but also to capture the contextual and practical dimensions underlying AI integration in educational settings.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Artificial Intelligence in Education

Artificial Intelligence (AI) refers to computational systems designed to perform tasks that typically require human cognitive abilities, such as recognizing patterns, processing natural language, generating predictions, and supporting data-driven decision support, without implying human-like understanding or reasoning (Luger & Stubblefield, 1993; Rich & Knight, 1991). Rather than replicating human intelligence, AI employs algorithms and statistical models to analyze large volumes of data, identify patterns, and generate outputs that assist users in performing complex tasks (Haag & Keen, 1996). In education, AI has evolved into an important technological tool that supports teaching and learning through applications such as personalized learning, learning analytics, automated assessment, and instructional assistance, thereby enhancing instructional efficiency and enabling more evidence-informed educational practices (Rojabi, 2025). Among its various applications, generative AI represents a subset of AI capable of producing new content, including text, images, code, and instructional materials, in response to user prompts. Because of its ability to assist teachers in lesson planning, content development, assessment design, and instructional support, generative AI has become one of the most widely adopted AI technologies in educational settings.

AI Utilization in Teaching

Recent studies indicate that the educational benefits of AI depend not only on the technology itself but also on teachers' ability to integrate it effectively into pedagogical practice. This capability is commonly explained using the Technological Pedagogical Content Knowledge (TPACK) framework, which conceptualizes teachers' knowledge as the integration of technological, pedagogical, and content knowledge to support effective teaching (Mishra & Koehler, 2006). Building on this framework, AI-TPACK extends TPACK by emphasizing teachers' competencies in integrating AI into instructional practice, highlighting the important role of digital competence in effective AI adoption (Hava & Babayiğit, 2025). More recently, Chiu (2025) proposed the Intelligent-TPACK (I-TPACK) framework, which positions AI literacy as a foundational competency that enables teachers to integrate technology, pedagogy, and content knowledge effectively within AI-supported learning environments. Although these frameworks differ in emphasis, they collectively explain how teachers transform AI technologies into meaningful pedagogical practices. Empirical evidence supports this perspective. Mulyani et al. (2025) demonstrate that the use of generative AI can enhance teaching performance by improving perceived usefulness, ease of use, and the quality of instructional materials, although technical challenges and the need for teacher training remain. Likewise, Tan et al. (2025a) found that the influence of AI on teacher performance is indirect and mediated through TPACK. Consistent with this finding, Hava and Babayiğit (2025) reported that stronger digital competence significantly enhances AI-TPACK, enabling teachers to integrate AI more effectively into learning. However, Aji et al. (2026) found that despite teachers' generally positive attitudes toward AI, their readiness and competency levels remain only moderate, limiting the effective implementation of AI in classroom practice.

In the context of education, a growing body of research suggests that AI can strengthen teachers' professional competencies and indirectly improve teaching performance through multiple developmental pathways. For example, Rahimi and Rezvani (2024) demonstrate that AI-supported professional learning strengthened teachers' TPACK, thereby improving their capacity to integrate technology effectively into pedagogical and assessment practices. Furthermore, Muslim al-Zyoud (2020) emphasizes that AI plays a role in supporting continuous professional development and improving teaching effectiveness, although its implementation remains constrained by infrastructure limitations and teacher readiness. This is reinforced by Duan and Zhao (2024), who found that AI not only enhances professional development but also fosters teachers' autonomy and self-directed learning while reducing digital burnout. From a conceptual perspective, Chiu (2025) developed the Intelligent-TPACK framework, which explains that AI literacy serves as a crucial foundation for simultaneously integrating technology, pedagogy, and content. Furthermore, Tan et al. (2025b) demonstrated in their intervention study that practice-based AI training programs can enhance AI competency and the ability to integrate AI into teaching. These findings are supported by Dogan et al. (2025), whose systematic review concluded that AI-based professional development effectively improves teachers' competencies and teaching practices when designed in a contextual and sustainable manner. Overall, this series of studies indicates that the use of AI holds significant potential for improving teacher performance; however, its impact is indirect and highly dependent on teachers' competencies, readiness, and adequate professional development support.

AI Utilization and Teacher Performance

The integration of artificial intelligence (AI) in education is increasingly linked to improved teacher performance, particularly in enhancing the effectiveness, efficiency, and quality of learning. Several studies indicate that AI-based learning environments can boost student engagement, motivation, and learning experiences, which ultimately impacts teaching effectiveness (Al Harrasi et al., 2025). Furthermore, the use of AI has also been shown to indirectly improve teaching effectiveness through teachers' perceptions of educational technology, underscoring the importance of cognitive factors and attitudes in AI utilization (Lin, 2022). From an evaluation perspective, AI-based systems enable more objective and continuous analysis of teacher performance through classroom interaction data (Almubarak et al., 2024, 2025). Furthermore, teaching quality also improves when AI use is supported by technology-based pedagogical competencies and teacher self-efficacy (Du et al., 2025). However, the role of AI in teacher education is not always straightforward, as it offers opportunities on one hand but also presents challenges on the other that may limit its impact on performance (Jamal, 2023). This indicates that while AI holds great potential, its influence on teacher performance is not necessarily consistent across various contexts.

A number of studies have also revealed inconsistencies in the relationship between AI use and teacher performance, which is influenced by various contextual and individual barriers. Challenges such as low readiness, limited digital competence, and a lack of institutional support are major factors hindering the integration of AI into teaching practices (Alshorman, 2024; Crompton et al., 2024; Ren & Wu, 2025). Additionally, structural barriers such as a lack of training and resistance to technological change further reinforce the limitations on teachers' adoption of AI (Ahmed et al., 2025; Al-Mughairi & Bhaskar, 2025). These conditions indicate that the impact of AI on teacher performance is significantly influenced by their level of readiness and competencies, particularly digital competencies and AI literacy (Dringó-Horváth et al., 2025; Galindo-Domínguez et al., 2024). In this context, professional development becomes a key factor that can bridge the gap between AI utilization and improved teacher performance, as it enhances both skills and technology-based pedagogical knowledge (Siyam et al., 2025). Furthermore, the TPACK framework emphasizes the importance of integrating technological, pedagogical, and content knowledge to support optimal teacher performance (Aktaş & Özmen, 2020). Therefore, the inconsistency in these findings highlights the importance of examining the role of professional development as a mediating variable in the relationship between AI utilization and teacher performance.

The Mediating Role of Professional Development

The use of artificial intelligence (AI) in education is growing and shows significant potential for improving teacher performance and supporting their professional development. AI can help teachers automate administrative tasks, analyze learning data, and provide pedagogical recommendations that can enhance the effectiveness of classroom learning. Celik et al. (2022) states that AI technology can support the teaching process through learning analytics, automated feedback systems, and personalized learning, which can improve the quality of teachers' instructional practices. In line with this, a study (Nemani, 2025) found that AI plays a role in improving teacher performance by reducing the administrative workload and allowing teachers to focus more on their pedagogical roles and learning mediation. Furthermore, research by Rao et al. (2025) indicates that the adoption of AI in education supports more personalized and data-driven learning, which ultimately leads to improved teaching effectiveness. This suggests that the utilization of AI can be a key factor contributing to enhanced teacher performance in the learning process.

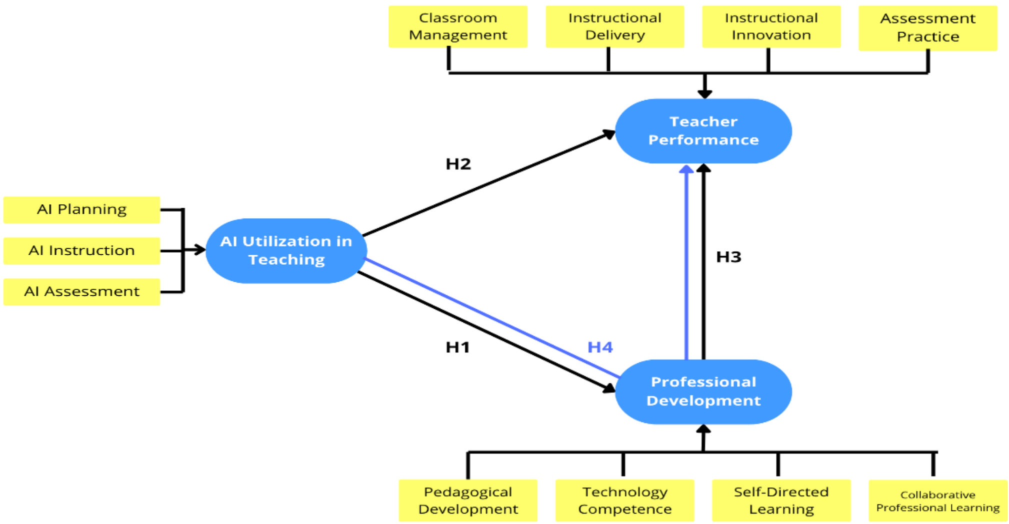

Figure 1. The research model (Source: Authors' own elaboration)

On the other hand, the use of AI is also closely linked to teachers' professional development, particularly in enhancing their digital and pedagogical competencies. Majeed and Ahmad (2025) indicates that the use of digital technology and AI contributes to the improvement of teachers' professional competencies through informal learning processes, technology-based training, and the exploration of digital learning resources. Furthermore, a study by (Bagdonaitė & Dagienė, 2025) confirms that the integration of AI in elementary and secondary education opens opportunities for teachers to develop new skills in the use of learning technologies and educational data analysis. Other research also indicates that AI can mediate the relationship between pedagogical competencies and teacher performance by providing analytical support and data-driven decision-making in the learning process (Baluyos et al., 2026). Thus, the integration of AI not only impacts the improvement of teacher performance but also serves as a crucial tool in strengthening the professional development process for teachers in the era of digital education.

Based on the theoretical foundations and prior empirical findings discussed above, the following hypotheses are proposed. The conceptual research model illustrating the relationships among the study variables is presented in **Figure 1**.

H1: AI Utilization in Teaching **is positively associated with** Professional Development.

H2: AI Utilization in Teaching **is positively associated with** Teacher Performance.

H3: Professional Development **is positively associated with** Teacher Performance.

H4: AI Utilization in Teaching **is positively associated with** Teacher Performance through Professional Development.

METHODS

Instruments

AI utilization in teaching

This study adopts the construct of AI Utilization in Teaching to examine teachers' actual practices in integrating artificial intelligence into their instructional work, shifting the focus from perception-based frameworks such as the Technology Acceptance Model (TAM), which primarily capture attitudes and intentions, toward observable and practice-oriented dimensions. Drawing on prior empirical and conceptual studies (Kong et al., 2024; Philippakos & Rocconi, 2025; Zawacki-Richter et al., 2019), AI utilization is conceptualized through three interconnected dimensions: AI Planning, AI Instruction, and AI Assessment. AI Planning refers to the use of AI in designing lessons, developing instructional materials, and aligning learning objectives with technological affordances. AI Instruction captures the integration of AI in facilitating student engagement, delivering content, and supporting differentiated learning processes. AI Assessment focuses on the use of AI to monitor, evaluate, and provide feedback on student learning.

By structuring AI utilization across these domains, this study moves beyond the predominantly attitudinal focus of earlier research and provides a more grounded understanding of how AI is operationalized in daily teaching practices. This approach enables a clearer examination of how teachers translate technological tools into meaningful instructional actions. It also highlights the importance of integrating AI across the full cycle of teaching rather than using it in isolated tasks. In this context, AI Utilization in Teaching is defined as teachers' capability to meaningfully integrate AI technologies across planning, instruction, and assessment functions. This construct is measured using seven items on a five-point Likert scale ranging from strongly disagree to strongly agree.

Professional development

This study conceptualized professional development as a multidimensional and dynamic construct that reflects teachers' continuous efforts to enhance their pedagogical, technological, and collaborative competencies in response to evolving educational demands. Rather than viewing it as a one-time training activity, this study emphasizes sustained, practice-oriented, and contextually relevant learning processes embedded in teachers' daily professional experiences. Drawing on Desimone (2009) as cited in Kang et al. (2013), as well as Mishra and Koehler (2006), Holmes and Tuomi (2022), and Knowles (1975), professional development is operationalized through four interconnected dimensions: Pedagogical Development, Technology Competence, Self-Directed Learning, and Collaborative Professional Learning.

Pedagogical Development captures teachers' engagement in meaningful learning experiences that strengthen content and pedagogical knowledge, while Technology Competence, grounded in the TPACK framework, reflects the ability to integrate technology into instructional planning, delivery, and evaluation. Self-Directed Learning highlights teachers' autonomy in continuously developing competencies, particularly in adopting and evaluating new technologies, whereas Collaborative Professional Learning emphasizes participation in knowledge sharing and collective professional growth. Together, these dimensions provide a holistic representation of professional development as an integrated and evolving process, measured using multiple items on a five-point Likert scale ranging from strongly disagree to strongly agree.

Teacher performance

This study measures teachers' instructional performance using the construct of teacher performance, which reflects the effectiveness of teachers in organizing classroom learning, delivering instruction, adapting teaching strategies, and assessing student learning outcomes. Rather than relying on self-perceptions, teacher performance is conceptualized as observable instructional practices that occur during the teaching and learning process. Drawing on previous empirical studies (Maulana et al., 2023; Shafii & Berger, 2025), this construct is operationalized through four key dimensions: Classroom Management, Instructional Delivery, Instructional Innovation, and Assessment Practice. Classroom Management, Instructional Delivery, and Instructional Innovation are adapted from the instructional quality framework underlying the International Comparative Analysis of Learning and Teaching (ICALT) developed by van de Grift (2007). These dimensions capture teachers' ability to manage learning environments effectively, deliver structured instruction, and adapt teaching strategies to meet diverse student needs.

The Assessment Practice dimension focuses on the implementation of formative assessment strategies during classroom learning, particularly in providing feedback that supports student progress. The indicators for this dimension are derived from Shafii and Berger (2025), emphasizing the role of formative assessment in improving learning outcomes. Together, these four dimensions provide a comprehensive and practice-based representation of teacher performance in classroom settings. This framework allows for a more objective evaluation of teaching effectiveness grounded in observable behaviors.

The complete measurement instrument, including the indicators, questionnaire items, corresponding references, and item numbering for each construct, is presented in **Appendix**.

Participants and Data Collection

The design of this study is explicitly categorized as a mixed-methods approach, rather than a quantitative study supplemented by qualitative interviews, because quantitative data serve as the primary phase for testing structural relationships among variables, while qualitative data are used in a subsequent phase to provide contextual explanations for the statistical results. The integration of these two approaches is carried out sequentially in accordance with an explanatory sequential design, in which the quantitative results are not only supplemented but also explained in depth through qualitative findings, thereby yielding a more comprehensive understanding of the phenomenon under study. This study employed a mix method research design with a cross-sectional survey approach to examine teachers' perceptions and their utilization of AI. The participants in this study consisted of 100 teachers in the Greater Blitar region, Indonesia. Participants were selected using simple random sampling to facilitate data collection. Data were collected using a structured questionnaire distributed via Google Forms, which included closed-ended questions and a Likert scale to measure respondents' opinions. Data collection was conducted both online, by distributing a questionnaire link, and offline, by visiting schools directly.

This study adopted an explanatory sequential mixed methods design, in which quantitative data served as the primary source, followed by qualitative data to provide deeper explanation and contextual understanding of the findings. This approach is consistent with the sequential explanatory design proposed by Ivankova et al. (2006), where qualitative data are used to explain and elaborate on quantitative results. After the quantitative analysis was completed, the survey results were used as the basis for selecting interview participants and developing interview guidelines. Thus, qualitative data were integrated with quantitative results through a process of "explanation building," in which interview findings were used to clarify and deepen the results of the statistical analysis.

Semi-structured interviews were conducted with two selected participants using a purposive sampling approach to gain in-depth insights. The two participants were selected based on the following criteria: (1) having experience using artificial intelligence in learning, (2) having participated in professional development activities, and (3) being willing to participate in the interviews. In this design, the interviews focused on exploring and clarifying the statistical results, rather than generalizing to the population. The number of interview participants was limited to two because the qualitative phase of this study aimed to provide a more in-depth explanation of the quantitative results, rather than making generalizations or developing new theories.

The study sample's demographic composition is shown in **Table 1**. The demographic profile of the sample indicates several notable patterns. Overall, these results indicate that the sample is dominated by experienced, adult teachers with moderate to

Table 1. Sample's demographic

Variables	Categories	Frequency	Percent
Gender	Male	25	25%
	Female	75	75%
Age (in years)	<21	-	
	21–30	17	17%
	31–40	36	36%
	41–50	29	29%
	51–60	16	16%
Teaching Experience	<5	16	16%
	5–10	17	17%
	11–20	43	43%
	>20	24	24%
Grade Level	Preschool	4	4%
	Elementary	46	46%
	Middle School	10	10%
	High School	43	43%
	Others	2	2%
AI Usage Frequency (in week)	Strongly Disagree	-	
	Disagree	12	12%
	Neutral	22	22%
	Agree	52	52%
	Strongly Agree	14	14%

high engagement in AI usage, which provides a relevant context for examining the relationship between AI utilization, professional development, and teacher performance.

Data Analysis

In this study, data analysis was conducted using SmartPLS software version 4 to perform Partial Least Squares Structural Equation Modeling (PLS-SEM) (Ringle et al., 2015). PLS-SEM is considered an appropriate approach for examining complex models with multiple dependent relationships simultaneously, particularly in studies aimed at prediction. Following the recommended PLS-SEM procedure, a two-stage analytical approach was applied (Hair et al., 2019). In the first stage, the measurement model was assessed by examining inter-item reliability, as well as convergent and discriminant validity. In the second stage, the structural model was evaluated to test the proposed hypotheses and determine the model's predictive capability (Hair et al., 2019).

This study applies the disjoint two-stage approach proposed by Becker et al. (2012) for estimating hierarchical component models in PLS-SEM, which is particularly suitable in PLS-SEM for analyzing complex or higher-order constructs that are formed by multiple lower-order dimensions. In this approach, higher-order constructs are not measured directly but are represented through underlying lower-order constructs, allowing for a more structured and accurate modeling process. In the first stage, the analysis focuses exclusively on the lower-order constructs, both exogenous and endogenous, while higher-order constructs are temporarily excluded. This stage aims to evaluate the reflective measurement models by estimating the relationships between indicators and their respective constructs, as well as generating latent variable scores. In the second stage, these latent variable scores are then used as new variables in the model, enabling the incorporation of higher-order constructs into the structural framework. This allows the researcher to examine the relationships between higher-order constructs and other variables more precisely. This two-stage procedure ensures a clearer estimation process and enhances the robustness of the structural model.

In addition to quantitative analysis using PLS-SEM, the semi-structured interview data were analyzed using thematic analysis. The interview data were first transcribed verbatim, then read repeatedly to gain a comprehensive understanding of the content. Next, the researcher conducted an open-coding process to identify units of meaning relevant to the research objectives. Codes with commonalities were then grouped into categories and developed into main themes representing teachers' experiences in utilizing AI. These themes were subsequently reviewed by comparing all interview data to ensure consistent interpretation. The results of the thematic analysis were used to explain, clarify, and deepen the quantitative findings, particularly regarding the mechanisms linking AI utilization, professional development, and teacher performance, in accordance with the explanatory sequential mixed methods design (Ivankova et al., 2006).

RESULTS

Quantitative Results

Reliability and validity

Table 2 presents the results of the assessment of convergent validity and construct reliability for the measurement model. Convergent validity was evaluated using factor loadings and Average Variance Extracted (AVE), while reliability was assessed through Composite Reliability (CR). The results indicate that all factor loadings exceed the recommended threshold of 0.70, demonstrating that each indicator adequately represents its strong, well-defined corresponding construct. Except for one item in Collaborative Professional Learning (factor loading =.69, nearing the .70 benchmark). According to Cheung et al. (2024), the

Table 2. Convergent validity Outer-Model: Reliability and Validity

Scales, dimensions, and items	Factor loadings	M	SD	CR	AVE
AI Utilization in Teaching Scale					
AI Planning (AIP)		4.01	.75	.87	.69
AIP1	.87				
AIP2	.86				
AIP3	.76				
AI Instruction (AII)		3.78	.82	.84	.72
AII1	.83				
AII2	.87				
AI Assessment (AIA)		3.85	.79	.91	.77
AIA1	.85				
AIA2	.85				
AIA3	.94				
Professional Development Scale					
Pedagogical Development (PD)		4.22	.64	.9	.68
PD1	.84				
PD2	.85				
PD3	.74				
PD4	.87				
Technology Competence (TC)		4.18	.59	.91	.71
TC1	.91				
TC2	.87				
TC3	.84				
TC4	.72				
Self-Directed Learning (SDL)		4.09	.68	.82	.69
SDL1	.79				
SDL2	.87				
Collaborative Professional Learning (CPL)		4.25	.52	.82	.7
CPL1	.69				
CPL2	.77				
Teacher Performance Scale					
Classroom Management (CM)		4.26	.52	.91	.77
CM1	.85				
CM2	.91				
CM3	.86				
Instructional Delivery (ID)		4.29	.53	.93	.75
ID1	.84				
ID2	.86				
ID3	.86				
ID4	.91				
Instructional Innovation (II)		4.34	.53	.9	.82
II1	.91				
II2	.90				
Assessment Practice (AP)		4.37	.5	.92	.86
AP1	.92				
AP2	.93				

construct was statistically significant and higher than 0.5. Moreover, CR values range from 0.82 to 0.93 surpassing the minimum acceptable level of 0.70 and confirming strong internal consistency. In addition, all AVE values are above 0.50, ranging from 0.68 to 0.86, which suggests that each construct explains more than half of the variance of its indicators. Overall, these findings confirm that all constructs satisfy the criteria for convergent validity and reliability, indicating that the measurement model is robust and appropriate for subsequent analysis.

Correlations and discriminant validity

Prior to evaluating discriminant validity using the Fornell and Larcker criterion, an initial assessment indicated that several measurement items did not satisfy the required discriminant validity standards. Therefore, a cross-loading analysis was conducted to identify indicators that exhibited stronger correlations with constructs other than their intended constructs. Indicators that did not meet the acceptable criteria, particularly those demonstrating excessively high correlations exceeding 0.90, were subsequently removed from the model. As a result of this refinement process, the number of dimensions was reduced from eleven to nine, and the total number of measurement items decreased from thirty-one to twenty-three. This procedure ensured that each retained indicator demonstrated a stronger association with its respective construct compared to other constructs within the model. Consequently, the refined measurement model presented in **Table 3** (Cross loading) consists only of valid indicators and is considered appropriate for subsequent analysis, particularly for hypothesis testing.

Table 3. Discriminant validity test Cross loading

	AIA	AII	AIP	CM	CPL	ID	PD	SDL	TC
AIA1	.89	.50	.74	.14	.05	.21	.03	.29	.14
AIA3	.85	.57	.49	.25	.33	.31	.12	.29	.23
AII1	.43	.83	.44	.25	.27	.26	.26	.30	.32
AII2	.60	.87	.44	.24	.38	.30	.23	.25	.16
AIP1	.69	.46	.87	.20	.17	.28	.13	.41	.25
AIP2	.60	.45	.86	.22	.11	.21	.03	.22	.24
AIP3	.47	.37	.76	.21	.26	.26	.25	.31	.31
CM1	.31	.40	.29	.88	.50	.70	.41	.40	.46
CM3	.08	.11	.16	.88	.36	.70	.33	.40	.48
CPL1	.28	.38	.22	.43	.81	.52	.40	.60	.62
CPL2	.08	.27	.14	.38	.86	.47	.83	.47	.48
ID1	.21	.29	.23	.73	.51	.85	.39	.52	.51
ID2	.28	.30	.26	.68	.54	.86	.44	.43	.50
ID3	.28	.28	.30	.65	.48	.88	.48	.45	.52
PD1	.11	.25	.11	.41	.67	.44	.84	.34	.46
PD2	.16	.32	.12	.43	.62	.48	.85	.39	.47
PD3	-.03	.18	.08	.26	.52	.33	.74	.31	.35
PD4	.02	.18	.18	.28	.66	.42	.86	.49	.51
SDL1	.11	.23	.30	.41	.45	.40	.29	.78	.52
SDL2	.41	.30	.33	.35	.59	.49	.47	.88	.63
TC2	.03	.18	.17	.44	.60	.47	.52	.53	.84
TC3	.22	.28	.31	.51	.53	.56	.47	.55	.88
TC4	.28	.24	.32	.36	.49	.44	.36	.65	.76

Table 4. Correlation of items and Fornell & Lacker test

	AIA	AII	AIP	CM	CPL	ID	PD	SDL	TC
AIA	.87								
AII	.61	.85							
AIP	.72	.52	.83						
CM	.22	.29	.25	.88					
CPL	.21	.39	.21	.48	.83				
ID	.30	.33	.30	.80	.59	0.87			
PD	.08	.29	.15	.42	.75	0.51	.83		
SDL	.33	.32	.38	.45	.63	0.54	.47	.83	
TC	.21	.28	.32	.53	.65	0.59	.55	.69	.83

Following the refinement process, **Table 4** (Fornell & Lacker) presents the relationships among the nine retained dimensions and demonstrates the ability of each construct to differentiate itself from the others. The results indicate that each dimension exhibits varying levels of correlation with other constructs, with coefficients ranging from 0.08 to 0.80. In terms of discriminant validity, the square root of the Average Variance Extracted (AVE) for each dimension, as shown on the diagonal elements, is greater than the corresponding inter-construct correlations. This finding confirms that each construct shares more variance with its own indicators than with those of other constructs within the model. Consequently, the measurement model satisfies the established criteria for discriminant validity, indicating that the instrument possesses adequate construct distinctiveness and is suitable for further analysis (Fornell & Larcker, 1981).

Structural equation model testing path result

Table 5 and **Figure 2** present the results of the structural model analysis, including path coefficients, standard deviations, t-values, and p-values used to assess the significance of the hypothesized relationships. The results show that AI utilization in teaching has a positive relationship with professional development ($\beta = 0.41$, $t = 4.765$, $p < 0.001$), supporting H1. However, the direct effect of AI utilization on teacher performance is not statistically significant ($\beta = 0.115$, $t = 1.175$, $p = 0.24$), leading to the rejection of H2. In contrast, professional development demonstrates a strong and significant effect on teacher performance ($\beta = 0.613$, $t = 7.03$, $p < 0.001$), supporting H3. These findings indicate that professional development plays a more dominant role in explaining variations in teacher performance compared to direct AI utilization.

Table 5. Inner-model: Structural equation model testing path result

Hypotheses	Relationships	*b*	STDEV	*T* |O/STDEV|	*P* values	Supported
H1	AI Utilization in Teaching → Professional Development	.41	.086	4.765	0	✓
H2	AI Utilization in Teaching → Teacher Performance	.12	.098	1.175	0.24	×
H3	Professional Development → Teacher Performance	.61	.087	7.03	0	✓
H4	AI Utilization in Teaching → Professional Development → Teacher Performance	.25	.068	3.675	0	✓

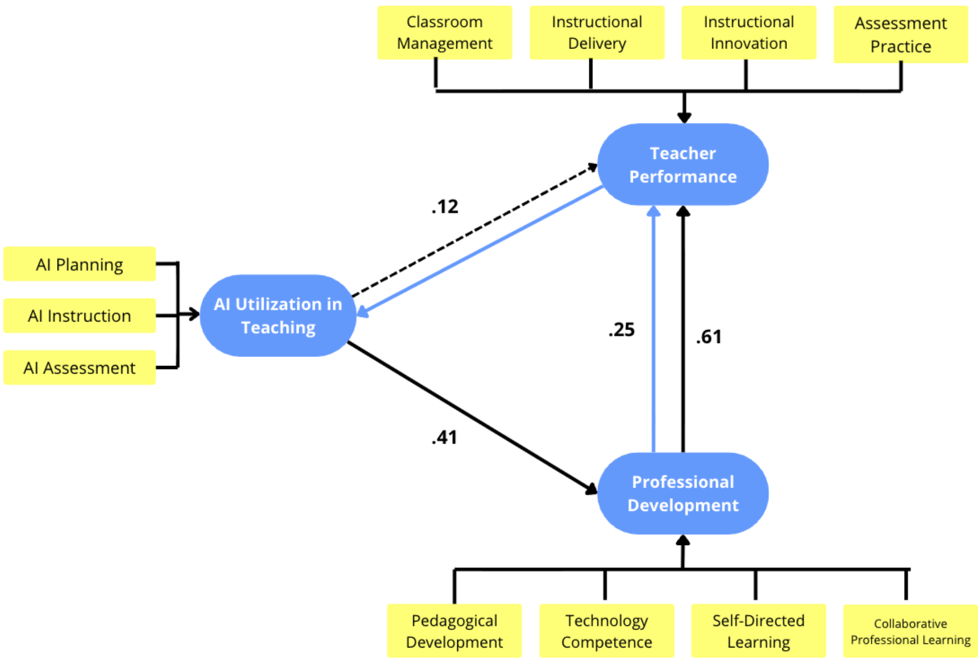

Figure 2. Results of the PLS-SEM analysis (Source: Authors' own elaboration)

Furthermore, the indirect effect of AI utilization on teacher performance through professional development is found to be positive and significant (β = 0.251, t = 3.675, p < 0.001), supporting H4 and confirming the presence of a mediating effect. This suggests that AI utilization contributes to teacher performance primarily through enhancing professional development rather than exerting a direct influence. Overall, three out of four hypotheses (H1, H3, and H4) are supported, while H2 is not supported. These results highlight the importance of considering indirect pathways in understanding the role of AI in educational contexts and demonstrate that professional development serves as a key mechanism linking AI utilization to improved teacher performance.

Qualitative Results

The qualitative findings were derived from semi-structured interviews with selected teachers to further explore their perceptions and experiences regarding the utilization of Artificial Intelligence (AI) in educational practices. The thematic analysis identified several recurring themes related to teaching efficiency, professional development, implementation barriers, and the role of teachers in AI-assisted learning. These findings complement the quantitative results by providing deeper explanations regarding how AI supports teacher performance indirectly through professional development.

The qualitative findings presented in this section are based on interviews with two purposively selected participants. Consistent with the explanatory sequential mixed methods design, these findings are intended to provide contextual explanations for the quantitative results rather than statistical generalization; therefore, the transferability of the qualitative findings is inherently limited.

Specifically, the qualitative phase provides an explanation for the quantitative findings, which indicates that the use of AI does not directly affect teacher performance but does so indirectly through professional development as a mediating variable. Through interviews, this study identified teachers' experiences in utilizing AI, the forms of professional development they participated in, and the factors that support and hinder the integration of AI into learning. These findings help explain the mechanisms underlying the relationships between variables, so that the quantitative results are not only interpreted based on statistical relationships but also understood through the real-world experiences and contexts faced by teachers.

Perceived benefits of AI for teaching efficiency

Interview findings indicated that teachers perceived AI as a practical and efficient tool for supporting instructional preparation, particularly in developing learning materials, assessment instruments, and classroom activities. Participants emphasized that AI reduced the time required for administrative and instructional planning tasks while also providing more varied teaching ideas.

> "The most helpful thing is when compiling questions and learning materials. So it's faster and you can get more variety of questions" (Informant 1)

> "Planning learning becomes easy, carrying out learning becomes fun, evaluating learning becomes fast." (Informant 2)

Both participants also highlighted that AI contributed to more engaging and structured learning processes. AI-assisted tools were frequently utilized to develop quizzes, modules, presentations, and instructional media that aligned with classroom needs.

> "I usually use it to make questions, compile teaching modules, find ideas for learning activities, and help make presentation materials." (Informant 1)

> "In AI teaching activities, I usually use it to make quizzes or questions, learning media, learning modules." (Informant 2)

These findings suggest that AI primarily enhanced teachers' efficiency in instructional preparation and administrative activities, particularly in planning and organizing learning materials.

AI and professional development

Participants consistently emphasized that effective AI utilization required continuous professional development. Teachers reported engaging in seminars, workshops, webinars, and independent learning activities to improve their understanding of AI integration in educational settings.

> "I feel the need to improve my capabilities, as technology continues to evolve." (Informant 1)

> "I have participated in several seminars, one of which is the seminar on the 'Designing Innovative Learning with AI at Gemini' Program." (Informant 2)

The participants further explained that practical and hands-on training experiences were more beneficial than theoretical explanations alone, as they enabled direct implementation in classroom contexts.

> "The most helpful is the training that is directly practiced, so you can try it right away." (Informant 1)

> "The most helpful development experience is the seminars, given examples of how to use." (Informant 2)

Additionally, both informants agreed that AI alone was insufficient to improve teaching performance without adequate professional competency development.

> "In my opinion, it is not enough to just use AI, it still needs professional development so that its use is appropriate." (Informant 1)

> "I don't think so, because yes, it still needs professional development." (Informant 2)

These findings indicate that professional development played an essential role in enabling teachers to maximize the pedagogical benefits of AI and adapt technological tools appropriately within instructional practices.

Challenges and limitations of AI integration

Despite acknowledging the advantages of Al, participants also identified several implementation challenges related to information reliability, infrastructure limitations, and contextual adaptation to students' characteristics. Teachers noted that Al-generated outputs could not always be directly applied in classroom settings without further evaluation and adjustment.

> "The problem is that sometimes the results of Al need to be adjusted again to the condition of students." (Informant 1)

> "Obstacles to the use of Al lack of infrastructure in the form of electronic devices and the internet, the truth of information." (Informant 2)

Participants also emphasized that differences in teachers' competencies, motivation, and institutional support influenced the effectiveness of Al adoption.

> "Not all teachers get the same benefits, because their abilities and willingness to learn are different." (Informant 1)

> "Not necessarily, it depends on the ability and determination of a teacher." (Informant 2)

Furthermore, the interview data revealed that inadequate training and lack of institutional support could hinder successful Al integration in teaching practices.

> "The risk is that teachers can be confused or misuse Al." (Informant 1)

> "The risk will not be realized because of the lack of support." (Informant 2)

These findings demonstrate that the effectiveness of AI integration remains dependent on teachers' competencies, technological readiness, and institutional facilitation.

Human role and pedagogical considerations in AI utilization

Another important theme emerging from the interviews concerned the continued importance of teachers' pedagogical roles despite increasing Al utilization. Participants consistently viewed Al as a supporting instrument rather than a replacement for teachers in classroom interaction and decision-making processes.

> "The important thing is that Al is just a tool. The role of teachers remains the main in the learning process." (Informant 1)

> "Al transforms work culture, sense of security, and teachers remain at the center." (Informant 2)

Both participants also explained that certain aspects of teaching performance, particularly classroom interaction and understanding student characteristics, remained highly dependent on teachers' personal experience and pedagogical competence.

> "For direct interaction with students not much has changed, because it still depends on the teacher's ability." (Informant 1)

> "The aspect of performance that does not change much after using Al is like facing the character of the student because it depends on the experience of a teacher's ability." (Informant 2)

These findings indicate that while Al contributes to instructional efficiency and administrative support, effective teaching performance continues to rely on human-centered pedagogical competencies and professional judgment.

DISCUSSION

The findings reveal a nuanced relationship between AI utilization, professional development, and teacher performance, underscoring that technology alone is insufficient without human capacity development. The significant relationship between AI utilization and professional development (H1) suggests that AI is a significant predictor of continuous learning rather than merely a technical tool. This finding supports Liu et al. (2026), who argued that AI shapes not only teachers' technical competencies but also their pedagogical beliefs, which are essential for meaningful instructional integration. From a theoretical perspective, this finding reflects a cognitive–behavioral pathway in which changes in teachers' beliefs predict subsequent teaching practices. The qualitative findings further strengthen this interpretation, as participants explained that their AI utilization evolved through continuous learning experiences such as seminars, workshops, and direct classroom implementation. Teachers emphasized that practical engagement with AI-supported learning activities improved their understanding of how AI could be integrated into instructional contexts. These findings indicate that AI utilization should not be viewed as a static technological adoption process but rather as part of a broader professional learning ecosystem that continuously shapes teacher competencies and instructional adaptation.

Despite this, the non-significant direct effect of AI utilization on teacher performance (H2) highlights a disconnect between technological adoption and measurable instructional outcomes. This finding challenges the assumption of technological determinism frequently implied in earlier studies, suggesting that the mere availability of AI tools does not automatically improve teaching performance. While previous studies such as Mulyani et al. (2025) and Wang et al. (2019) reported positive effects of AI utilization on teaching outcomes, the current findings indicate that these effects remain conditional upon pedagogical integration and teacher competency. The qualitative results demonstrated that teachers primarily utilized AI to support technical and administrative tasks, including developing quizzes, learning modules, presentations, and instructional materials. Although these practices improved instructional efficiency, participants also acknowledged that classroom interaction and student engagement remained largely dependent on teachers' pedagogical abilities and experience. This indicates that AI contributes more strongly to instructional preparation than to transforming core teaching practices. Therefore, the effectiveness of AI integration depends less on the frequency of use and more on the extent to which AI is meaningfully embedded into instructional design and pedagogical decision-making processes.

The strong relationship between professional development and teacher performance (H3) reaffirms the central role of teacher competency in shaping instructional quality and educational effectiveness. This finding aligns with Mduma and Mkulu (2021), who emphasized that sustained professional training enhances teacher effectiveness while reducing instructional challenges. Even within technology-rich educational environments, human capital remains the dominant factor influencing performance outcomes. The findings also support competency-based educational frameworks in which teacher performance emerges from accumulated pedagogical knowledge, technological skills, reflective practice, and continuous learning. Similarly, Tan et al. (2025a, 2025b) identified Technological Pedagogical Content Knowledge (TPACK) as a significant predictor of effective teaching performance. The qualitative findings reinforce this argument, as teachers consistently emphasized the importance of seminars, workshops, and practical training experiences that enabled them to directly apply AI tools within classroom contexts. Participants also highlighted that theoretical explanations alone were insufficient without hands-on implementation opportunities. These findings indicate that professional development should be understood as a continuous and integrative process rather than isolated training interventions.

The mediating role of professional development (H4) provides an important contribution by clarifying the pathway through which AI utilization is associated with teacher performance. Rather than exerting a direct effect, AI contributes indirectly by strengthening teachers' competencies, pedagogical readiness, and technological integration skills. This finding supports studies conducted by Tan et al. (2025a, 2025b) and Ning et al. (2024), both of which emphasized the importance of competency integration frameworks such as TPACK in translating technology utilization into effective instructional practice. Within this framework, AI functions as a technological input, while professional development acts as the transformation mechanism that converts technological access into improved instructional performance. The qualitative findings further support this interpretation, as participants emphasized that AI utilization without adequate professional training could lead to ineffective or inappropriate application in classroom settings. Teachers also stressed that practical training experiences enabled them to adapt AI-generated outputs according to students' characteristics and instructional needs. These findings demonstrate that the educational benefits of AI are not automatic but depend heavily on structured professional learning processes and pedagogical adaptation.

Furthermore, teacher readiness and digital competence emerged as critical conditions influencing the effectiveness of AI integration in educational settings. Previous studies by Kurdal and Kaplan (2026) and Hava and Babayiğit (2025) highlighted the importance of digital literacy in supporting meaningful AI engagement. Without adequate technological competence, AI risks being either underutilized or misapplied within instructional contexts. This finding is consistent with Yue et al. (2024), who identified a gap between positive attitudes toward AI and actual readiness to implement it effectively. The qualitative findings revealed several barriers related to infrastructure limitations, unreliable internet access, limited electronic devices, and concerns regarding the accuracy of AI-generated information. Participants also emphasized that differences in teachers' competencies, motivation, and willingness to learn significantly influenced the effectiveness of AI adoption. Moreover, teachers noted that insufficient institutional support and lack of training opportunities could hinder successful AI implementation. These findings indicate that teacher readiness should not be considered a peripheral issue but rather a structural prerequisite for sustainable AI integration. Consequently, improving AI utilization requires not only individual competency development but also institutional investment in infrastructure, policy alignment, and long-term professional support systems.

In addition, the findings suggest that AI itself can function as a facilitator of professional learning, thereby creating a reciprocal relationship between AI utilization and teacher development. Bonk et al. (2026) argued that AI tools can support self-directed learning, reflective practice, and idea generation, positioning AI not only as a teaching aid but also as a learning environment for educators. The present findings support this perspective, as teachers reported increased efficiency, flexibility, and adaptability in instructional preparation after integrating AI into their professional practices. Participants explained that AI simplified lesson planning, accelerated evaluation processes, and provided alternative instructional ideas that could be adjusted according to classroom needs. These experiences illustrate how AI contributes to continuous learning by enabling teachers to access and construct pedagogical knowledge more efficiently. The findings are also consistent with Al-Zyoud (2020), who emphasized the role of AI in supporting adaptive and personalized professional development. Therefore, AI integration extends beyond classroom instruction and contributes to broader teacher learning ecosystems that promote continuous competency enhancement.

Finally, this study challenges the assumption that technological innovation alone can drive educational improvement. The findings clearly demonstrate that without structured professional development, the impact of AI on teacher performance remains limited. This supports the perspective that educational transformation is fundamentally human-centered, where technology functions primarily as an enabling instrument rather than the main driver of change. The qualitative findings strongly reinforce this interpretation, as participants consistently emphasized that AI serves only as a supporting tool while teachers remain central to instructional interaction, pedagogical judgment, and classroom decision-making processes. Teachers also explained that important aspects of teaching performance, particularly understanding student characteristics, managing classroom interaction, and responding to learners' needs, continued to depend on human experience and pedagogical competence rather than technological assistance. These findings indicate that sustainable educational improvement requires alignment between technology, pedagogy, teacher competency, and institutional support. Consequently, the study advocates a shift from technology-centered approaches toward teacher-centered AI integration models that prioritize professional development, pedagogical readiness, and contextual instructional adaptation.

CONCLUSION

This study shows that AI utilization is not directly associated with teacher performance but demonstrates an indirect relationship through professional development as a mediating mechanism. These findings suggest that the relationship between AI utilization and teacher performance may depend on teachers' continuous professional development. Theoretically, this study reinforces the view that technology-based educational transformation remains centered on human capacity, not on technology alone. Practically, the research results emphasize the importance of professional development programs integrated with AI training, institutional support, and infrastructure readiness so that AI implementation can have a tangible impact on the quality of learning. Nevertheless, this study is still limited by its cross-sectional design, relatively small sample size, and specific regional context; therefore, future research is recommended to use a longitudinal design with a broader sample scope and to consider other variables such as digital literacy, self-efficacy, and institutional support in explaining the effectiveness of AI integration in educational settings.

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review & editing; **FAY:** validation, supervision, writing – review & editing; **RDH:** supervision, writing – review & editing. All authors agreed with the results and conclusions.

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AI statement: The authors stated that ChatGPT, powered by the GPT-5.5 model, was used during the preparation of this manuscript to support language refinement, improve academic expression, and assist in organizing ideas. The AI tool was not used to generate research content, develop hypotheses, analyze data, interpret findings, or replace the authors' scholarly judgment. All AI-assisted outputs were critically reviewed, verified, and revised by the authors, who remain fully responsible for the accuracy, originality, and integrity of the manuscript.

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APPENDIX

Table A1. Item survey instruments for this research

Variable	Reference	Indicator	Item	Number
AI Utilization in Teaching (X)	Philippakos and Rocconi (2025); Zawacki-Richter et al. (2019)	AI Usage Intensity (Demographic)	I use AI in my learning activities every week.	1
		AI Planning	I use AI to help develop modules, teaching materials, or presentation materials.	2
			I use AI to help create practice questions.	3
			I use AI to help create or find ideas for games, videos, or visuals as learning media.	4
	Kong et al. (2024); Philippakos and Rocconi (2025); Zawacki-Richter et al. (2019)	AI Instruction	I engage students in the use of AI in learning activities.	5
			I use AI to help meet the diverse needs of students in learning.	6
		AI Assessment	I use AI to help develop learning evaluation instruments such as assessments or student worksheets.	7
			I use AI to help provide feedback on student work to make it more engaging.	8
			I use AI to help provide feedback on my teaching to make it more understandable and in-depth.	9
Professional Development (Y1)	Desimone (2009) in Kang et al. (2013)	Pedagogical Development	I participate in training that deepens my understanding of the teaching material.	10
			I actively participate in discussions, reflections, and practices during the training.	11
			The professional development program I participate in is aligned with the learning needs of my school.	12
			The training I attend is ongoing, not a one-time event.	13
	Holmes and Tuomi (2022); Mishra and Koehler (2006)	Technology Competence	I am able to integrate technology into the learning process.	15
			I understand how to use technology to support learning strategies.	16
			I use technology to assist in learning planning and evaluation.	17
			Technology helps me improve the quality of decisions in learning.	18
	Knowles (1975)	Self-Directed Learning	I independently study the use of technology to enhance my competency.	19
			I independently evaluate the effectiveness of technology use in my teaching practice.	20
	Desimone (2009) in Kang et al. (2013)	Collaborative Professional Learning	I share my experiences using technology with fellow teachers through digital platforms.	21
			I participate in professional development activities with fellow teachers.	14
Teacher Performance (Y2)	Maulana et al. (2023)	Classroom Management	I can guide students smoothly from one activity to the next.	22
			I am able to effectively handle student disruptions or behaviors so that the learning process continues.	23
			I manage learning time well, ensuring all activities are completed on schedule.	24
		Instructional Delivery	I convey learning materials clearly and easily understood by students.	25
			I structure learning from the introduction, main points, to the conclusion in a structured and logical manner.	26
			I actively engage students in the learning process, encouraging participation and interaction.	27
			I use learning strategies that are appropriate to the goals and characteristics of students.	28
		Instructional Innovation	I adapt learning activities based on students' abilities, interests, or specific needs.	29
			I provide a variety of methods and materials so that all students can learn effectively.	30
	Shafii and Berger (2025)	Assessment Practice	I use formative assessment (including AI) to monitor student progress throughout the learning process.	31
			I provide constructive feedback and help students improve their understanding.	32