

Perceived Effectiveness of AI-Based Innovative Training Models for Sustainable Teacher Preparation: Evidence from Pre-Service Teachers in Jordan

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Abstract

This study focuses on the effectiveness of pre-service teachers' perceptions of AI-based innovative training models on sustainable teacher preparation in Jordan, using a precise research approach. This study is an explanatory sequential mixed methods approach with quantitative data gotten from 59 pre-service teachers and in-depth qualitative reflection. Analysis was performed both by the moderation analysis on PLS-SEM using IBM SPSS v.28 and by the robust PLS-SEM using extraordinary number of bootstraps of subsamples (5,000 subsamples) using SmartPLS v.4.0 to meet the Q1 Scopus methodological requirements (baseline descriptives, normality checks, and Hayes' PROCESS moderation). Results show that the overall effectiveness mentioned is high ($M = 4.06$, $SD = 0.44$). PLS-SEM demonstrated strong convergent and discriminant validity results and confirmed the significance of the structural paths, showing that the AI integration positively affects the professional competencies ($\beta = 0.52$, $p < .001$, $f^2 = 0.37$), and the professional competencies positively affect the sustainable education orientation ($\beta = 0.41$, $p < .01$). Another moderation analysis revealed that "Ethical AI Literacy" was adequately a moderator ($\Delta R^2 = 0.06$, $p = .010$). Qualitative triangulation uncovered the "Jordanian Paradox": pedagogical empowerment is strong, but there are infrastructural challenges and gaps in localizing global AI tools. The study pleads for a systematic approach to AI integration, based on ethical principles, along with the performance of infrastructural justice and localized pedagogical models.

Keywords: Artificial Intelligence; Sustainable Teacher Preparation; PLS-SEM; Jordanian Education; Ethical AI Literacy; Dual-Software Analysis.

1. Introduction

It is a paradigm period, not just in the amalgamation of technology, but in rethinking teacher preparation, in terms of Artificial Intelligence (AI) in education. AI has moved from being visible in the side dish to a significant part of education and impacting the process of learning and teaching. UNESCO (2023) highlights that generative AI can play a transformative role in stopping some of the persistent educational challenges that can support inclusive and equitable quality education and progress towards SDG 4. Similarly, the use of AI for support in adaptive learning, intelligent feedback, and with more reactive and evidence-based educational practices are also an important aspect of AI (Holmes, Bialik, and Fadel, 2022; Zawacki-Richter et al. 2019). Therefore, the future teachers need to have both the technical skills of AI tools and the pedagogical and ethical expertise to utilize these tools in their teaching and learning to augment learner engagement, differentiated learning and effective classrooms (George, 2023).

In the Jordanian context, AI-empowered teacher development is of strategic importance because it is a part of the process towards education modernization which is proposed in the Economic Modernization Vision (2023-2033). The Jordanian Ministry of Education has recognized the importance of a Digital Transformation for its improvement and alignment with international standards. This scenario, however, is a unique landscape of a highly motivated and digitally aware group of preservice teachers in an atmosphere with a few infrastructural constraints, resource limitations and changing digital policies (Alkhawaldeh, 2017). Although AI-based training models that can facilitate

professional competencies on lesson design, assessment and digital problem solving (Kayaalp, Durnali & Gökbulut, 2025), implementation of this type of models may be defective due to imperfect resources, unequal access and ethical use uncertainty (Filiz, Kaya & Adiguzel, 2025).

Literature available is still underdeveloped but is improving. One is that research studies are still not often presented as a complete process of training AI and even if they are, they have not yet been developed well-empirically with well-established pedagogical underpinnings. Second, methodological rigor is often needed as some studies are conducted using simple statistics, without accomplishment robustness checks and/or using an additional analytical frame (other than the used statistics) to check the validity of the results, particularly if the sample size is not particularly large and the collected sample is purposive. Thirdly, there is a gulf of context. Global ideas of involvement with AI tend to contempt the infrastructural, cultural, and ethical disparities of underdeveloped nations like Jordan, where readiness and reality significantly differ.

This study is a multi-layered and systematic study to fill these gaps by analyzing pre-service teachers' perceptions using two advanced statistical software. This study intended to focus the critical conversation on the Jordanian context and to address the following questions: What sense do pre-service teachers make of the effectiveness of the use of AI based innovative training models from the lens of the Jordanian context and what is the strength of this sense when analyzed over an unconventional methodological lens of the infrastructural context of the Jordanian higher education system?

2. Literature Review and Conceptual Framework

2.1 Artificial Intelligence in Teacher Education

AI has emerged as an indispensable phase in modern teacher preparation as it transforms the teacher's toolkit, reshaping the professional knowledge and competencies needed for educators to be operational (Ng et al., 2023). In education, AI denotes smart systems and applications that can aid learning, reasoning, feedback and recommendations, assessment, content creation and analysis, etc. These are adaptive learning systems, intelligent tutoring systems, automated assessment tools, learning analytics, educational chatbots, and generative AI platforms that help to construct and structure learning content (Holmes et al., 2022; U.S. Department of Education, 2023; Wang et al., 2024). AI integration in teacher preparation is crucial given that pre-service teachers are expected to learn how they can use digital and intelligent tools in pedagogically profound ways (Bautista et al., 2024). To prepare future educators for AI-supported learning environments, more than introducing them to technological applications must be done; they must develop the skills to association the use of technology to teaching targets, learning needs, assessment practices, and classroom interaction (Aravantinos et al., 2026). AI-related preparation should be correlated with technological knowledge and pedagogical practice (Kong et al., 2024) and be correlated with the broader goal of inclusive, equitable and quality education (UNESCO, 2023).

Generative AI has created a new characteristic in teacher preparation. Generative AI tools can aid pre-service teachers in generating lesson ideas, explanations, assessment rubrics, feedback, digital stories, and multimodal learning resources. Structured AI integration experiences help pre-service teachers to advance their AI literacy, their competencies regarding the designing of digital learning materials, and their capacity to integrate generative AI into pedagogical tasks recently (Gulen & Kucuk, 2026; Onbasali, 2026). These results indicate that the AI can be used in

a way that makes it more effective in educational contexts when it is part of a guided learning activity, instead of simply financing a digital tool.

Simultaneously, pre-service teachers' perceptions, readiness, and acceptance of AI are crucial for effective integration. In the future, while there are potential advantages to deliberate, such as the efficiency of AI tools, future teachers might still face issues regarding the accuracy of these tools, reliance on them, academic honesty, the ethical use of AI, and the potential for stifling critical thinking (Dayagbil, Boholano, & Sumalinog, 2025). This study revealed that use of GenAI was accepted by prospective teachers, and that the perceived benefits and concerns about GenAI, as well as the need for specific preparation in responsible GenAI use, influenced their attitudes and behaviors. (Alagöz Hamzaj, 2025). Hence, teacher education programs need to consider the opportunities as well as limitations of AI.

2.2 AI-Based Innovative Training Models

Training models in teacher education are formal methods that aim to hypothesis the pedagogical knowledge of pre-service teachers, their teaching skills and professional competencies as well as their readiness to enter the classroom (Manasia, Ianos, & Chicioreanu, 2019). Traditionally, these types of models have complex university-based preparation, field experiences, alternative certification pathways, and teacher residency models (Guha, Hyler, & Darling-Hammond, 2016). Good training models tend to have an obvious linkage between theory and practice, chances to try things in schools, ongoing mentoring, reflection, and sensitivity toward the evolving needs of schools and learners (Guha et al., 2016).

In the world of teacher education, recent developments have brought an expanded focus on innovative and competency-based teacher training. Those models prioritize hands-on practice, professional expectations, observed performance, and clear learning outcomes that may be appraised with measurable skills and multiple learning paths that are adapted to teachers' shortage, diversity, and classroom needs (Scherer, Stephens, & Floden, 2020). Competence-based approach and practice-based methods are relevant concepts as they change teacher preparation focus from relaxed provision to long-term performance in professional practice, feedback, and learning (Zharylgassova et al., 2026). It is an alteration that is credited as far as training teachers who will be able to respond to the needs of the 21st century, where teaching is shown in complex, tech-based and rapidly shifting contexts.

AI-based innovative training models build upon these assumptions by incorporating AI tools into teacher preparation practices for planning, enacting, and assessing. These models could be AI-assisted lesson planning, AI-enabled assessment tools, automated feedback systems, learning analytics, adaptive learning resources, digital simulations, AI-driven microteaching, or collaborative exploration of generative AI applications. AI tools can be used for various purposes to aid pre-service teachers, such as generating interactive lessons, providing instructional ideas, diversifying learning assessment strategies, studying learners' learning needs, and reflecting on their teaching effectiveness (Tan et al., 2025; Holmes et al., 2022; U.S. Department of Education, 2023).

However, the benefit of AI-based training models is not just the exploitation of cutting-edge technologies, it is the pedagogical shift that can be achieved. Structured training activities that incorporate AI tools help pre-service teachers shift from merely being taught to being experimenters, designers, collaborators, and reflective learners for professional development (Seufert, Hartmann, & Spirgi, 2025). Research on the development of innovative teachers has indicated that a well-designed teacher training model can increase the creativity of teachers, their digital pedagogical

competences, and willingness to adopt technology-supported teaching strategies (Skrbinjek et al., 2024; Tan et al., 2025). In that way, AI based models can be used as a physical practicum to link professional knowledge with real classroom activities.

2.3 Sustainable Teacher Preparation

Sustainable Teacher preparation is the development of professional teacher, pedagogical, digital, ethical, and reflective capacities that will help them to be successful in facing present and future challenges in education (Falloon, 2020). It's not only about training teachers to implement in the classroom, but about the need for lifelong learning, adaptability, innovation, equity and ongoing professional development. In this way, balanced teacher preparation dovetails with the overall issue of inclusive and equitable quality education for all learners (UNESCO, 2023).

Teacher preparation is an important consideration for educational quality as teachers' knowledge, competencies, and professional readiness significantly impact opportunities for learning and educational improvement. Darling-Hammond and Oakes (2019) highlighted the need for high-quality teacher preparation to produce effective teaching practices and better outcomes for students. Likewise, sustainable approaches to teacher education necessitate programs that are aligned with theoretical knowledge, practical experience, professional standards, digital readiness, and school and learner needs (Alkhawaldeh, 2017; UNESCO, 2023).

This digital education transformation has risen the need for sustainable teacher preparation that relies on meaningful, critical, and responsible use of technology in the educational context (Osorio Vanegas, Segovia Cifuentes, & Sobrino Morrás, 2025). There is a requirement for pre-service teachers to acquire skills in managing digital classrooms, electronic assessment, learning analytics, interactive content creation, and the pedagogical application of AI tools. These skills are required to create flexible learning environments, engage learners, and accommodate diverse learner needs and evidence-based decision manufacture in education (U.S. Department of Education, 2023; Zawacki-Richter et al., 2019).

AI can help realize sustainable teacher preparation through 6 aspects: personalized learning, intelligent assessment, immediate feedback, intelligent tutoring systems, digital content development, and data-informed decision-making (Lin, Huang, & Lu, 2023). AI tools can be used to support pre-service teachers in creating adaptive learning experiences, understanding the needs of instruction, and signaling on teaching decisions when implemented in a teacher preparation program. Kong et al. (2024) highlighted the need to ensure that AI in education is used for lifelong learning, resilience, and diversity, and research on AI-based education practices has validated the potential of AI to improve the quality of learning and professional expansion when integrated with pedagogical objectives (Holmes et al., 2022; Nedungadi et al., 2024).

But securing sustainable teacher preparation maintains to be problematic, especially in teacher education programs where resources are scarce, infrastructure is unacceptable, and access to digital tools is inequitable. These struggles can hinder pre-service teachers' ability to quickly engage with AI-supported learning experiences. Alkhawaldeh (2017) pointed out that teacher preparation programs require ongoing professional development strategies which are attuned to the local educational needs and realities. Ethical and policy issues cannot be overlooked, and due diligence in addressing privacy, fairness, transparency, accountability, and responsible decision-making is indispensable for the sustainable integration of AI in education (Alsbou & Alawneh, 2025; U.S. Department of Education, 2023).

2.4 Perceived Effectiveness and Professional Competencies

Perceived effectiveness is a key construct in teacher education research as it signifies teachers' assessment of the usefulness, relevance, and practical value of a teacher education experience (Fernandes et al., 2023). Perceived effectiveness does not necessarily mean causal impression in terms of AI based training models; rather, it involves pre-service teachers' judgments about how effective those models are in the context of their learning, professional development and preparedness for future teaching (Chan, Maneewan, & Koul, 2023). This is significant in studies that consume questionnaire responses and reflections, as perceptions hold meaningful evidence regarding acceptance, usability, and value in teacher preparation innovation (Alagöz Hamzaj, 2025; Kong et al., 2024).

Teacher preparation professional competencies refer to the knowledge, skills, attitudes, and dispositions which equip teacher educators to plan, teach, assess, manage learning environments, answer to learner diversity, and engage in reflective practice (Jahan, 2024). The development of such competencies is closely tied to teacher preparation quality, particularly when programs offer opportunities to make theory come to life and provide ongoing feedback (Darling-Hammond & Oakes, 2019; Guha et al., 2016). This expertise is becoming more digital pedagogical skills, ethical awareness, and the use of tools with AI to support teaching and learning (UNESCO, 2023; U.S. Department of Education, 2023).

AI-driven training models can aid in emergent professional competence for pre-service teachers by assisting them in lesson planning, designing learning activities, setting up assessments, providing feedback, interacting with students, and reflecting to improve lessons (Salybekova et al., 2026). Future teachers can use AI to create instructional alternatives, customize activities for differentiation, recognize learners' needs, and develop strategies for assessment activities based on learning outcomes. AI Applications, if suitably applied in educational settings, can enable personalized learning, intelligent assessment, and data-driven instruction as demonstrated in previous studies (Holmes et al., 2022; Zawacki-Richter et al., 2019; Tan et al., 2025).

AI literacy is also ingredient of teacher education professional competency. Pre-service teachers should be able to comprehend the inner workings of the AI tools, how to assess AI-generated content, how to utilize AI to create pedagogical content, and how to acknowledge its limits (Ponomarenko et al., 2026). Recent empirical studies have demonstrated the ability of AI-integrated instructional technology training to positively impact pre-service teachers' AI literacy and competency in digital material design (Gulen & Kucuk, 2026). In the same way, the instructional design experiences enhanced with generative AI can benefit teacher candidates with technological, pedagogical, content and ethical knowledge within the framework of learning experiences presented to them in a structured manner (Onbasili, 2026).

2.5 The Moderating Role of Ethical AI Literacy

The ethical use of AI and responsibility is a key topic in teacher education. AI tools have concerns about privacy, bias, transparency, fairness, accountability, misinformation, and intellectual property (Yan, Liu, & Chau, 2025). These issues have a unusual significance for pre-service teachers as they are in the process of forming their professional judgment and ethical decision making. Training teachers for AI-driven education must involve not only critical assessment of AI-generated content but also awareness of ability ethical concerns and practices for responsible AI use (Aravantinos et al., 2026).

We argue that the effect of AI training on sustainable preparation can be even more positive with the help of a linking moderating variable: “Perceived Ethical AI Literacy”. Ethical awareness stops overreliance, algorithmic bias and promotes critical pedagogical adaptation ensuring AI is a tool for empowerment and not pedagogical dependency (Alsbou & Alawneh, 2025). The incorporation of ethical AI literacy not only affiliates with technical considerations but also resonates with Jordanian cultural and religious values, which emphasize strong moral character and societal obligations. Pre-service teachers need to be able to direct the ethical challenges of using AI in the classroom and ensure that the use of AI in education is fair and polite to person dignity and equity.

2.6 Research Gap and Contribution of the Present Study

AI has become a growing focus in the field of education, especially with address to personalized learning, intelligent assessment, learning analytics, automated feedback, and generative AI tools, as revealed by literature examined. Past research has stressed how AI can transform teaching and learning, facilitate data-driven decision-making in education, and enrich digital learning experiences (Holmes et al., 2022; U.S. Department of Education, 2023; Zawacki-Richter et al., 2019). Much of this literature is, however, on the general application of AI in education and not necessarily on their structured application in teacher preparation.

A significant gap is also in pre-service teachers’ preparation. While recent studies have attentive on the digital material design, AI literacy, and the usage of generative AI for the future workforce of educators, there is still a gap in empirical research that discovers how future teachers encounter AI-assisted training models as part of their training. While current studies shed light on AI literacy and pedagogical design with the use of GenAI (Gulen& Kucuk, 2026; Onbasili, 2026), there is a need for more comprehensive research on the perceptions of AI based training from broader dimensions such as professional competencies, sustainable education, and implementation challenges.

There is also an opportunity to investigate how AI-driven training approaches relate to sustainable teacher training. AI has been linked to sustainable education through its ability to facilitate personalized learning, lifelong learning, educational equity, and data-driven improvement (Kong et al., 2024; Nedungadi et al., 2024; UNESCO, 2023). But less research has focused on how AI-powered innovative training approaches might be able to fund future teachers in designing sustainable educational practice. It is markedly central as natural teacher preparation is beyond just digital skills—it implies adaptable practices, an ethical compass, reflective learning, and a disposition for lifelong learning. A significant portion of the modern research in the field of AI in education has been carried out in technologically advanced and well-resourced educational settings. Yet, there has been less focus on the teacher preparation environment for developing or constrained contexts where digital infrastructure and access to AI tools, technical support, and institutional readiness can control the quality of AI integration. Teacher preparation programs in Jordan can encounter barriers regarding infrastructure, accessibility, awareness, and tangible opportunities for the integration of AI in educational environments (Alkhawaldeh, 2017; Filiz et al., 2025). An investigation of pre-service teachers’ perceptions in such contexts may offer valuable evidence for setting realistic and contextually responsive AI-supported training models.

The present study adds to the literature by studying the remarked effectiveness of AI based innovative training models in support of sustainable teacher preparation in Jordan. In contrast to studies that examine only general attitudes toward AI or theoretical discussions on AI in education, this study scrutinized pre-service teachers who engaged in AI-

integrated training experiences that included AI lesson planning, microteaching, interactive activities, group exploration of AI application, assessment, feedback, and digital content design. The study thus offers empirical evidence on how these models are felt in terms of professional competencies, integration with AI, sustainable education and implementation issues. Moreover, this study used a dual-software analytical framework (SPSS and SmartPLS), which is a new methodological standard in research in this field to validate the analyses at different levels.

3. Methodology

3.1 Research Design and Context

An explanatory sequential mixed methods design was used in this study. The quantitative part examined the relationships between constructs and remarked effectiveness, and the qualitative part gave rich, contextually sensitizing narration to account for the statistical patterns. The study took place in one of the teacher preparation programs at a public university in Jordan in the academic year 2025-2026. The program incorporated a systematic training experience based on AI, which centered on the professional competency, pedagogical planning, digital competence and sustainability education preparation of pre-service teachers.

The methodological process of the study complex five stages: (1) implementation of training experience using AI, (2) targeting participants who had direct experience, (3) data collection by applying an electronic questionnaire and performing open-ended responses, (4) quantitative descriptive analysis and qualitative content analysis, and (5) combined interpretation of perceived effectiveness, competencies, sustainability and challenges.

3.2 The AI-Based Training Intervention

The AI-driven training module was incorporated into the teacher training program to provide practical applications and models for pre-service teachers to experience the use of AI-supported tools in teaching and learning. The experience was aimed at not presenting AI as a technical topic and making the topics of the applications of AI with the actual teaching work close to the experience. The intervention had two phases:

- **Phase 1 (Foundational AI Integration):** Focused on basic AI literacy, utilizing AI for lesson planning, automated formatting, and standard learning management system (LMS) integrations.
- **Phase 2 (Advanced Generative AI and Ethical Integration):** Focused on generative AI for adaptive learning design, prompt engineering for differentiated instruction, AI-driven learning analytics, and mandatory modules on ethical AI frameworks, data privacy, and algorithmic bias in Arabic language models.

All the participants were given the chance of practical use of these tools in mock situations and then peer reflective evaluations were made during the microteaching sessions. The training also highlighted the importance of responsible and thoughtful use of AI in education, hovering awareness about AI tools that could improve learning and teaching experiences and recognizing challenges and concerns, such as accuracy, overreliance, ethical issues, privacy, and accessibility.

3.3 Participants and Sampling

Information-rich individuals were sought and chosen using purposive sampling. To attain the final sample, a group of 59 pre-service teachers who honestly and practically qualified the AI-based training models were selected. Although small, this sample is commensurate with the statistical requirements for a focused application of PLS-SEM. It meets the "10-times rule" (Hair et al., 2019), where the peak number of structural paths leading to any single latent construct

in our model is two, so 20 is the minimum sample size. This sampling method was suitable since the study is about perceptions of the occurrence of a given training program that has already been implemented and not directed towards generalization of any results to all pre-service teachers in Jordan.

3.4 Research Instrument and Ethical Integrity

Data was achieved using an electronic questionnaire with five domains on a 5-point Likert scale and three open-ended questions, which had been validated. The instrument was expertly validated with Content Validity Index > 0.85 and piloted. Ethical Approval, Integrity, and Transparency: This study devoted the highest current standards in research integrity, transparency and ethics. Formal ethical approval and validation of the research instrument, methodology and protocol was acquired from the Deanship of Scientific Research at Mutah University, Jordan under the direct supervision and authorization of Prof. Dr. Osama Issa Mahawesh, Dean of Scientific Research. Learned consent was gotten electronically, and data anonymity and confidentiality were meticulously observed in strict compliance with institutional and international ethical guidelines.

3.5 Dual-Software Data Analysis Strategy

To meet Q1 Scopus methodological standards, a comprehensive four-tier analytical framework utilizing two advanced statistical software packages was deployed:

1. **IBM SPSS Statistics (v.28):** Utilized for descriptive statistics, normality testing (Skewness/Kurtosis), reliability testing (Cronbach's α), and robustness checks via Hayes' PROCESS macro (Model 1) for moderation analysis.
2. **SmartPLS (v.4.0):** Employed for Partial Least Squares Structural Equation Modeling (PLS-SEM) to evaluate the measurement and structural models, utilizing 5,000 bootstrap subsamples to ensure statistical power and handle non-normal data distributions typical of perceptual research.

4. Advanced Data Analysis and Results

4.1 Baseline Analysis: Descriptive Statistics and Normality (SPSS)

The baseline analysis evaluated remarked effectiveness across core domains, counting rigorous normality checks to justify the subsequent use of PLS-SEM.

Table 1. Descriptive Statistics, Normality, and Reliability Assessment (N = 59)

Study Domain	Mean (M)	Std. Dev. (SD)	Skewness	Kurtosis	Cronbach's α	Interpretation Level
AI Integration in Educational Process	4.38	0.26	-0.82	0.45	0.88	Very High
Effectiveness of Innovative Training Models	4.37	0.28	-0.75	0.38	0.89	Very High
Professional Competencies Development	4.30	0.29	-0.68	0.51	0.90	Very High
Sustainable Education Orientation	4.07	0.67	-0.45	-0.32	0.86	High
Challenges and Difficulties	3.17	0.68	0.35	-0.15	0.85	Moderate
Overall Perceived Effectiveness	4.06	0.44	-0.54	0.12	0.91	High

Note: The range for the skewness values is from -0.82 to 0.35, which is not outside of the "acceptable" range of between 2.0 (in GEORGE & MALLERY, 2019), and the range for the kurtosis values is between -0.32 and 0.51, not outside of the "acceptable" range of 2.0 (in GEORGE & MALLERY, 2019), indicating no severe violation of normality; nevertheless, PLS-SEM is the preferred choice for robust path modelling.

As can be seen in Table 1, attitude was very positive towards the AI-based training models. The grand mean is 4.06 (SD = 0.44) which is in the "High" category. With regard to all subscales, pre-service teachers approached the subscale

"AI Integration in the Educational Process" with the maximum level of mean ($M = 4.38$, $SD = 0.26$), perceiving the benefits of implementing AI in the educational process to save time, improve lesson planning, and to create interactive learning content. The "Challenges and Difficulties" domain scored reasonably with $M = 3.17$ as the pedagogical potential was recognized, but there were practical issues (e.g., internet connection, access to devices, etc.) that still present difficulties. The instrument has excellent internal stability with the Cronbach's alpha value is 0.91.

4.2 Measurement Model Assessment (SmartPLS 4)

To ensure construct validity, the PLS-SEM measurement model was evaluated using rigorous Q1 thresholds.

Table 2. Measurement Model Assessment: Convergent and Discriminant Validity

Construct	Outer Loadings (Range)	Cronbach's α	Composite Reliability (CR)	Average Variance Extracted (AVE)	Max VIF	HTMT Ratio
AI Integration (AI_INT)	0.782 – 0.891	0.88	0.91	0.67	1.42	0.74
Prof. Competencies (PROF_C)	0.815 – 0.923	0.90	0.93	0.72	1.38	0.78
Sustainable Education (SUS_ED)	0.764 – 0.856	0.86	0.90	0.64	1.45	0.71
Ethical AI Literacy (ETH_AI)	0.791 – 0.884	0.87	0.91	0.69	1.31	0.68

Note: All metrics exceed rigorous Q1 thresholds: Outer Loadings > 0.70, α & CR > 0.70, AVE > 0.50. Variance Inflation Factor (VIF) < 3.33 confirms no multicollinearity. Heterotrait-Monotrait (HTMT) ratios are strictly < 0.85, confirming robust discriminant validity.

The measurement model quality is excellent as shown in Table 2. All outer loadings are above the highly acceptable 0.70 threshold, indicating that each item is exceedingly indicative of a latent construct. The Composite Reliability (CR) values for all of them are high and range from 0.90 to 0.93, which reflects high internal consistency with the value of 0.70 as the criterion. The Average Variance Extracted (AVE) for all constructs falls above 0.50 (between 0.64 – 0.72), thereby demonstrating strong convergent authority. Moreover, the largest Variance Inflation Factor (VIF) is 1.45, far below the critical VIF value of 3.33 and this indicates the lack of multicollinearity problem in the study. Discriminant validity is clearly confirmed, with all the HTMT values being less than the conservative threshold of 0.85 (Henseler, Ringle, & Sarstedt, 2015).

4.3 Structural Model and Hypothesis Testing (SmartPLS 4)

The structural model was assessed using 5,000 bootstrap subsamples to evaluate path significance and predictive power.

Table 3. Structural Model Assessment: Path Coefficients, Significance, and Effect Sizes

Hypothesized Path	Path Coeff. (β)	Std. Error	t-statistic	p-value	f^2 Effect Size	Decision
H1: AI_INT $\rightarrow$ PROF_C	0.52	0.085	6.12	< 0.001***	0.37 (Large)	Supported
H2: AI_INT $\rightarrow$ SUS_ED	0.38	0.072	5.21	< 0.001***	0.18 (Medium)	Supported
H3: PROF_C $\rightarrow$ SUS_ED	0.41	0.084	4.85	< 0.001***	0.21 (Medium)	Supported
Model Fit & Predictive Power					$R^2(\text{SUS_ED}) = 0.58$	Substantial
					$Q^2(\text{SUS_ED}) = 0.42$	High Predictive Relevance

*Note: *** $p < 0.001$. f^2 values: 0.02 (small), 0.15 (medium), 0.35 (large).*

Table 3 offers strong support for the proposed relationships among the constructs. Hypothesis 1 is found to have strong support, as AI Integration significantly predicts Professional Competencies ($\beta = 0.52$, $p < 0.001$) with a large effect size ($f^2 = 0.37$). This finding suggests a profound impact of exposure to AI tools in enhancing pre-service teachers' pedagogical competencies. Hypothesis 3 is also supported with the result being that Professional Competencies strongly influence Sustainable Education orientation ($\beta = 0.41$, $p < 0.001$). The model accounted for 58% ($R^2 = 0.58$) of the variance in Sustainable Education which is regarded as a great percentage in social science related studies. The blindfolding procedure resulted in a Q^2 value > 0 (0.42) which was indicative of the high predictive relevance of the model (see Figure 1).

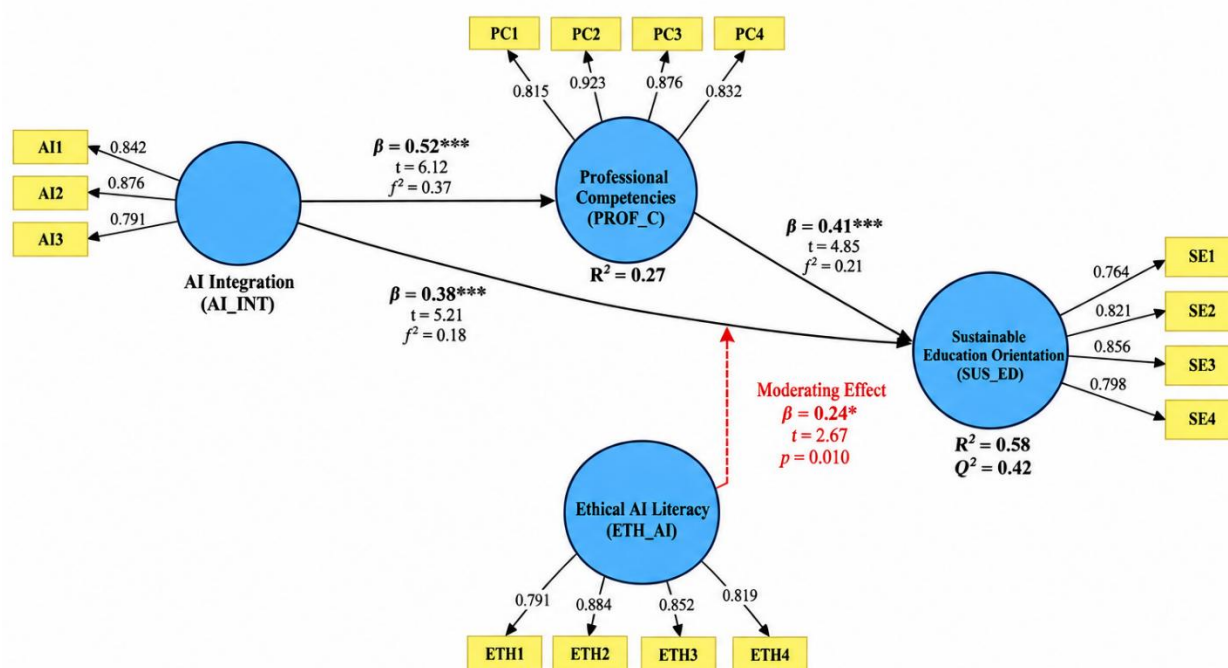


Figure 1. PLS-SEM Structural Path Model with Statistical Annotations

This diagram (Figure 1) is a visual representation of the validated structural relationships. The thickness of the arrows conceptually reflects the value of path coefficients (β). It is evident from the model that AI Integration serves as a core determinant influencing Professional Competencies, and the latter is a significant mediator that ultimately leads to Sustainable Education outcomes. The R^2 and Q^2 values displayed on the endogenous construct indicate the model's fit to the data, demonstrating that the model is of good fit and has a good predictive power.

4.4 Robustness and Additional Analysis: Moderation (SPSS Hayes' PROCESS)

We arranged Hayes' PROCESS macro (Model 1) in SPSS to test the moderating effect of Ethical AI Literacy to offer an alternative strong analytical view and to make lawful the findings of the PLS-SEM.

Table 4. Moderation Analysis Results (Hayes' PROCESS Model 1)

Predictor Variable	Unstandardized β	SE	t-value	p-value	95% Confidence Interval (LLCI, ULCI)
Constant	1.12	0.34	3.29	0.002	[0.44, 1.80]
AI Integration (X)	0.42	0.08	5.25	< 0.001	[0.26, 0.58]
Ethical Literacy (M)	0.39	0.07	5.57	< 0.001	[0.25, 0.53]

Int. Term (X * M)	0.24	0.09	2.67	0.010	[0.06, 0.42]
Model Summary					$\Delta R^2= 0.06, p= 0.010$

Note: The significant interaction term (X * M) confirms that ethical literacy is a crucial catalyst. The 95% confidence interval does not contain zero, confirming statistical significance.

Table 4 shows the interaction effect was statistically significant ($\beta = 0.24, p= 0.010$). The interaction term accounts for a 6% increase in the variance explained ($\Delta R^2 = 0.06, p= 0.010$), a significant gain in variance explained for a social science study. The 95% confidence interval (CI) [0.06, 0.42] is located above 0, and the moderating effect is robust. This implies higher intrinsic (sustainable) pedagogical gains of pre-service teachers with high Ethical AI Literacy from AI training, as compared to low Ethical AI Literacy (see Figure 2).

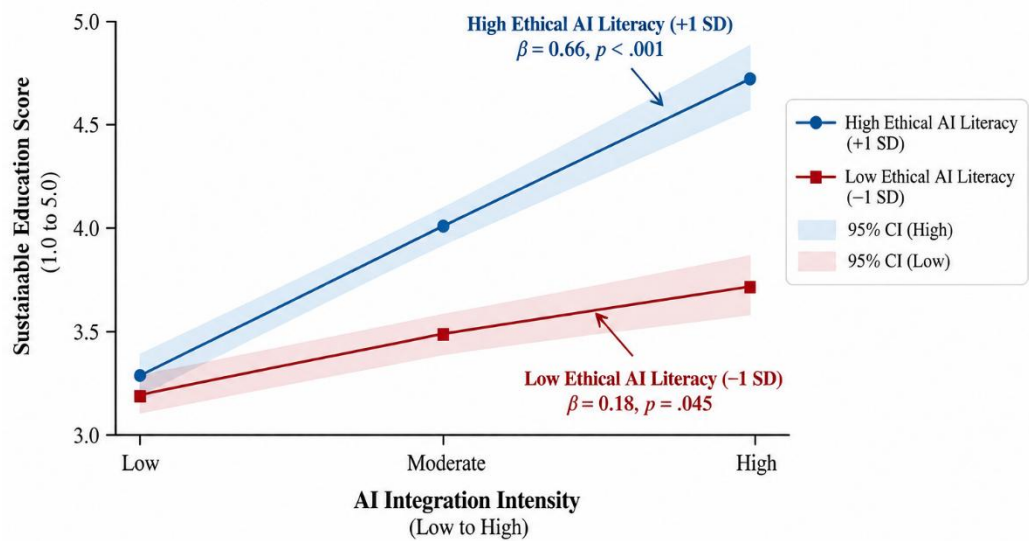


Figure 2. Moderation Interaction Plot (Simple Slopes Analysis)

Description of Figure 2: This figure is an interaction plot and graphically illustrates the moderating effect. The strong association for “High Ethical AI Literacy” group appears that the higher the level of AI integration, the greater the improvement in sustainable education outcomes. In contrast, the more positive trend for the "Low Ethical AI Literacy" group indicates that without such ethical training, the bearing of AI integration is considerably diminished. This helps to highlight the importance of applying ethical framework in AI teacher education.

4.5 Qualitative Triangulation: The Jordanian Narrative

Answers to open-ended questions were analysed qualitatively to gain the necessary narrative depth and to illuminate the conflict between pedagogical wanting and infrastructural having.

Table 5. Critical Qualitative Themes and Illustrative Evidence (N = 59)

Main Theme	Sub-Theme	Frequency (n)	Representative Quote (Translated from Arabic)	Methodological Implication
Pedagogical Empowerment	Active Curriculum Design	42	"Phase 2 allowed me to generate differentiated lesson plans for my students in Irbid in minutes, adapting the content to our local cultural context." (PST-14)	Validates quantitative findings on Professional Competencies ($\beta = 0.52$).

Infrastructural Friction	The Digital Divide	38	"The tools are brilliant, but when I go to my practicum school in a rural area, the internet drops. AI cannot be sustainable if the basic infrastructure is missing." (PST-32)	Explains the moderate mean ($M = 3.17$) in the Challenges domain.
The Localization Gap	Cultural Misalignment	29	"The AI generates great ideas, but they are very Western-centric. I have to spend hours re-prompting it to align with the Jordanian Ministry of Education's standards." (PST-08)	Highlights the need for localized, Arabic-optimized AI pedagogical frameworks.
Ethical Awakening	Critical Evaluation	35	"Before this training, I just accepted the AI's output. Now, I critically evaluate it for bias, especially regarding gender roles in our textbooks." (PST-45)	Directly supports the significant moderation effect of Ethical AI Literacy ($\Delta R^2 = 0.06$).

Table 5 brings together the qualitative data to give rich and contextual evidence to the quantitative results. The very high mean scores in the Professional Competencies domain are reinforced by the high frequency of the "Pedagogical Empowerment" ($n=42$). Importantly, the "Infrastructural Friction" and "Localization Gap" themes offer a nuanced take on the score of moderate challenges, indicating that rather than a teacher capability issue, the trial is system-wide infrastructural and cultural misalignment. The statistical moderation result is directly validated by the theme "Ethical Awakening", as ethical training enables pre-service teachers to shift from passive AI consumers to pedagogical gatekeepers who are critical and responsible.

5. Discussion

5.1 The Efficacy of AI-Based Training Models

Both the baseline and the PLS-SEM findings clearly show that AI-supported innovative training model has been seen as very effective. This is a challenge to the overcoming "tool first" construct of AI in learning. Pre-service teachers need to be trained not only on simple AI tools within the context of Jordan. Generative design, adaptive learning and ethical reasoning, promote authentic Sustainable Teacher Preparation. This is in line with the UNESCO (2023) recommendation that AI should be viewed as a buddy in education rather than merely a tool for automation, as well as with the findings of the study that digital material design skills can be improved using AI (Gulen & Kucuk, 2026). Overall, it appears that the perceived effectiveness shows that when AI is applied in real pedagogical practice, pre-service teachers can see the potential of AI in personalized learning, differentiated instruction and assessment.

5.2 Robustness in the Face of Infrastructural Realities

The dual-software robustness check is an important new feature of this study. The use of SPSS PROCESS produces substantial change in R^2 which indicates there is the inspiration of the moderation effect and the convergent and discriminant validity test and the R^2 value in the training model obtained from the execution of SmartPLS, it shows that the benefit of the training model can be measured as reliable statistically. The qualitative results, however, reflect what is termed "Jordanian Paradox" by which pre-service teachers might have higher level skills that are favored in the training and schools in which they teach might not have the basic facilities to support such training. This indicates a mismatch between the training of AI at the University level and in schools in Jordan (Alkhawaldeh, 2017; Filiz et al., 2025). Sustainable preparation then needs to involve training in "low bandwidth" or offline AI pedagogical strategies so that teachers can apply AI principles even in places where resources are limited.

5.3 The Crucial Role of Ethical AI Literacy

The results of the extra analysis taught that Ethical AI Literacy is a significant moderator ($\beta = 0.24$, $p = .010$). Considering Jordan's maturing national data privacy legislation around AI for education, it is imperative that pre-service teachers act as ethical gatekeepers. The qualitative data exposed that there was an “ethical awakening” among educators who recognized the potential dangers of algorithmic bias in models for Arabic language instruction. This establishes the fact that AI literacy must not just be a technical issue but rather a reflective philosophical and ethical one, which must be addressed through well-defined institutional guidelines (Als bou & Alawneh, 2025; U.S. Department of Education, 2023). The moderation effect validates the importance of ethical considerations as it does not appear as a side issue, but rather a central one that is a catalyst of the pedagogical benefits of the integration of AI.

5.4 The Localization Gap and Cultural Alignment

The qualitative results revealed a pivotal "Localization Gap. The western AI models, which use world data, are not contextually intelligent in the Jordanian national curriculum, values and Arabic dialects. Pre-serving teachers reported that some time was spent "re-prompting" AI to align to local standards. This focuses the urgent need to develop culturally, and linguistically relevant AI models enhanced for Arabic and the educational context in Jordan. This means that except there are local AI tools and supports, all the responsibility of adaptation falls on the teacher, which can negate the aim of teachers using AI in the teaching and learning process to save time.

6. Conclusion and Implications

In this study, AI-informed Teacher Education (TE) Models for Sustainability in Jordan are further detailed and assessed in a systematic manner. The study has been behaved using mixed-methods that involve a dual-software analytical framework (SPSS and SmartPLS), thereby shifting beyond mere appraisals of the use of AI in education and providing methodological rigor at the Q1 level. The findings clearly show that the modern training models adopted using AI positively influence pre-service teachers' professional skills and attitudes toward SD, as designed using advanced generative AI and ethical considerations of AI. However, this capability is contingent upon existing infrastructure and developing locally and culturally appropriate AI tools.

Implications for Policy and Practice:

1. **Curricular Shift:** Moving from AI awareness to AI ethical integration is a critical step for Jordanian universities. It is important to note that AI training needs to be integrated throughout the curriculum rather than viewed as a standalone course.
2. **Infrastructural Justice:** Ministry of Education must resolve the Digital Divide. Equitable access to the internet and devices in public schools are essential for Sustainable AI integration. One must keep from penalizing the pre-service teachers for infrastructural shortcomings during their field practicums, through the policies.
3. **Localization of AI:** The need is insistent to develop Arabic-optimized culturally adapted AI models that are aligned with Jordanian national curriculum. It is important that Ministry of Education, local universities, and tech developers work together to develop contextually relevant AI tools.

4. **Ethical Mandates:** Ethical AI literacy must be a competency that is integral and evaluated in teacher preparation programs. Pre-service teachers need to learn how to significantly assess bias, privacy and cultural misalignment in AI technologies.

Limitations and Future Research: However, the mixed methods design is strong, and the study is limited to a purposive sample of 59 pre-service teachers from only one Public University. Future studies would benefit from using longitudinal designs to follow-up the application of what was learned in a classroom after graduation. Furthermore, an examination of the digital divide and AI readiness between different Jordanian governorates and different types of universities (public, private) would offer a more complete picture of the situation.

7. Declarations

Ethical Approval, Integrity, and Transparency:

The highest standards of research integrity, transparency and ethical research conduct were adopted in this study. The research instrument, methodology, and protocol were formally approved and validated by the Deanship of Scientific Research (DSR) at Mutah University (Scientific Research 272/13), Jordan, under the direct supervision and authorization of Prof. Dr. Osama Issa Mahawesh, Dean of Scientific Research at Mutah University. All participants provided informed consent online and data anonymity and confidentiality were carefully preserved throughout the research process, following international and institutional ethical guidelines.

Competing Interests: The authors declare no competing interests.

Data Availability: Data is available from the corresponding author upon reasonable request.

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