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Utilizing Artificial Intelligence to Optimize Professional Development for 21st Century Teachers

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Abstract

The rapid growth of educational technologies, as well as evolving classroom dynamics, necessitates that 21st-century educators constantly improve their instructional techniques. However, traditional "one-size-fits-all" professional development (PD) programs frequently fail to address individual teachers' different, specific requirements, resulting in poor engagement and limited classroom impact. This article investigates the use of artificial intelligence (AI) as a revolutionary driver for improving teacher professional development. Modern PD platforms may transform static seminars into dynamic, individualized learning systems by integrating AI-driven analytics, natural language processing, and machine learning algorithms. This study investigates the integration of artificial intelligence (AI) into professional development (PD) programs for 21st-century teachers, aiming to assess its impact on self-efficacy and satisfaction. Utilizing a quantitative research design, data were collected from 80 in-service teachers through a structured Likert-scale questionnaire. Results indicate a moderate positive correlation between AI integration and teacher self-efficacy ($r = 0.27$, $p < .05$) as well as satisfaction ($r = 0.34$, $p < .01$). The ratings of the participants about the AI-infused PD experiences were positive, with the tools that supported the participants with real-time feedback, individualized learning trajectories, and adaptability. But when independent-samples t-tests were used, the pairs did not significantly differ in the overall satisfaction or self-efficacy between teacher participants of the AI-integrated PD and those who did not take part in it. Item-level analysis established that the ability to track progress and make personal recommendations were the most strongly associated features with the perceived professional growth. The findings also indicate that the presence of AI in PD may not be of essence alone but the characteristics and capabilities of AI tools do play an important role in changing the perception of the teachers and the manner in which they learn. This study argues that incorporating AI into teacher education not only modernizes professional development but also directly corresponds with better student learning outcomes, providing a scalable model for systemic educational transformation and emphasizing the importance of proactive, thoughtful and morally sound AI-PD construction and how this conclusion applies to both policymakers and educational managers interested in upgrading their teacher development work.

Keywords: Artificial intelligence, professional development, teacher self-efficacy, TPACK model, digital pedagogy

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Background of the Study

Teachers must constantly adapt to the demands of the 21st-century educational atmosphere, but traditional approaches of professional development frequently fail to meet the needs of individual teachers. By embracing Artificial Intelligence, educational institutions can shift toward highly individualized, data-driven, and adaptive training frameworks that enhance teacher progress in real-time. So, this paradigm changes permits educators to develop the dynamic capabilities needed for contemporary classrooms while also improving pedagogical skills. The integration of AI developments from disciplines like natural language processing and computer vision into education has become a popular research topic (Lo, 2023; Mai et al., 2024). Through tools like chatbots, AI-assisted learning platforms, data-driven decision support systems, and learning behavior analysis tools, among others, academics have increasingly investigated how these AI technologies can improve the teaching and learning process (Zhang & Aslan, 2021; Tang et al., 2023). The field of education is actively looking into how AI might change instruction.

The incorporation of artificial intelligence (AI) into professional development (PD) for educators marks a turning point in the educational environment. With education systems all over the world attempting to face the difficulties of the twenty-first century, the traditional one-size-fits-all approach to teacher preparation is no longer regarded adequate. Teachers are currently confronted with the fast-changing face of technology, varied demands of the students, as well as the need to constantly acquire new skills throughout life. Teachers are under pressure to keep up with automation in this age of rapid technological advancement, which means that traditional teaching methods will need to be replaced with multi-stimulant learning environments using AI tools (Sarwar et al., 2026). Artificial intelligence (AI) has the potential to alter education by providing tailored learning, increased student engagement, and enhanced educational efficiency (Bhutoria, 2022, Dickler, 2021, Edwards & Cheok, 2018, Gobert et al., 2023). AI systems such as the Inquiry Intelligent Tutoring System (Inq-ITS) demonstrate this by tracking student learning progress, delivering individualized learning feedback, and automating assessments with fast grading (Gobert et al., 2023). AI transforms higher education by personalizing learning directions, building intelligent tutoring systems, accelerating research, and improving classroom management efficiency (Bobula, 2024).

AI has led to a transition in university teaching from teacher-centered to collaborative approaches (Celik, 2023a). There is a lack of guidance frameworks for teachers to redesign courses using real-time learning analytics, manage classroom interactions with intelligent agents, and use AI-driven formative assessment to track learning outcomes (T. C. Nguyen, 2023; Balatero et al., 2024; Hur, 2024; Younis, 2024). Teachers can create a strong foundation of AI principles and familiarize themselves with common application situations through structured professional development (Mah & Martín, 2024). Hence, this encourages them to use AI technology. Teachers can then learn how to use various AI educational technologies in the classroom with the use of training designs based on practical operation and case analysis (Benedicto et al., 2023). In addition, through peer support, professional feedback, and successful experiences, professional development programs can lessen teachers' technical stress. This will strengthen their positive attitudes and confidence toward AI technology and increase their initiative in constantly experimenting with new tools (Wei & Sun, 2024).

Introduction

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AI presents an attractive pathway toward the revolutionization of PD with the help of personal, scalable, and expanded data tools. The advent of generative AI (GenAI) and intelligent tutoring systems has transformed what tools are available to educators and what competencies educators now need to have. In this way, the reconsideration of PD through the AI paradigm is not just relevant, but the necessary one to provide teachers with relevant and dynamic as well as practical skills. The need to match PD with AI literacy has recently received support in scholarly discussions of the urgency of the matter. Instead of being consumers of technology, teachers will find that they will be critical facilitators in the learning environments that help to integrate, adapt, and facilitate continuous learning among students who make use of AI. According to Brandao, Pedro, and Zagalo (2024), AI literacy should serve as one of the fundamental pillars in PD which would require not only its technical definition, but ethical, pedagogical, and curricular implications. Their integrative review finds three primary elements of successful PD in terms of AI integration: conceptual awareness of AI, practical work with GenAI instruments and instructional strategy formation on the basis of ethical and critical attitude. When integrated in the training of teachers, these elements allow educators to use AI not only purposefully but also instill responsible use of the technology in students.

AI can make an impact on how teachers learn far beyond what is related to literacy. In that regard, Doan and Nalbantooglu (2025) suggest PD programs based on the Technological Pedagogical Content Knowledge (TPACK) framework and infused with AI have been proven to have the potential of enhancing teachers to have an integrated awareness of technology, pedagogy, and content. The systemic review they provide makes it clear that PD designs which include AI tools including chatbots, adaptive learning platforms, and intelligent analytics represent significant advancements in instruction planning, classroom interaction, and formative assessment. Furthermore, they emphasize how successful AI-PD programs are the ones encouraging collaboration, iterative learning and reflective practice, which these conventional models lack in common.

In conjunction with the growing number of AI tools, there is a necessity to ensure the strong assessment of AI competence among teachers. The Artificial Intelligence Literacy (AIL) Scale was created and tested by Younis et al. (2025) to allow educators to assess their capabilities of applying AI in the classroom scenario. They included a sample of educators of the six countries and got the results that AI competence differed greatly depending on working experience and the subject that was taught. The results reaffirm that various PD pathways that will meet a different AI readiness level are essential. By not differentiating, there is a risk that PD may frame and further the digital divide rather than bridge it in the education system.

Besides the measurement of AI literacy, Delcker, Heil, and Ifenthaler (2024) also justify the need to learn more about self-perceptions of AI competencies. They have revealed six different indicators of an AI competence amongst vocational educators and identified the necessity of the focus on these aspects intensifying confidence and effective use of AI technologies through their study. Such dimensioned perception of teacher readiness will enable the more customizable and effective PD design, paving the way to easier transition between awareness and implementation.

The aspect of creativity development is also a crucial sphere in AI-related PD. Liubarska (2024) states that AI implemented during the educational process of teachers not only raises the competencies in instruction but also develops creative ability. With the

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help of the AI programs like generative storytelling and scenario-building, PD is able to inspire educators to be more experimental regarding pedagogical innovations. These kinds of practices enhance activities and make teachers ready to instill creativity on their students, which is one of the competencies in the skill set in the 21st century. Having said that, the study should also warn that uncontrolled use of AI can pose a risk to the human aspects of teaching, such as empathy, critical judgment, and the cross-relational dynamics of teaching-learning, which should achieve a delicate balance in PD between opportunity and warning.

He and Zhou (2025) also add to dwell on the pedagogical implications of AI in PD touching upon AI-enhanced mentoring in teacher preparation. These results indicate that the empirical research proves that procedural knowledge and reflective practice of teachers can be enhanced significantly using simulated teaching tasks involving AI. More importantly, computers high-performing teacher candidates indicated intricate mentoring game plans enabled by AI, implying that immersive or AI-mediated facilitating can make it possible to develop more profound teaching knowledge. This style allows a transition away from content delivery toward the acquisition of pedagogical versatility and flexibility, qualities that are ever more important components of the energetic classroom setting.

One cannot omit the ethical aspects of AI integration into PD. Mouta, Torrecilla-Sanchez, and Pinto-Llorente (2024) reiterate that teachers should not only acquire the technical part of knowledge but rather have the critical ability of examining the consequences of AI in terms of learner control, data confidentiality, and algorithm discrimination. They present their educational design studies in compliance with the idea that PD programs must incorporate ethical inquiry with the use of case studies, situation-based teaching and discussion in a group setting. By doing this, they do not place teachers as mere recipients of the available technologies, but rather active participants regarding control over the morality of AI in the educational field.

Such artificial intelligence-powered PD is also quite multifaceted in the matters of inclusivity and diversity. As an example, Zhang and Xiong (2025) explore the posthumanist issues of AI in education and focus on the tensions related to the teacher identity, agency, and pedagogical roles. According to their results, PD should also teach teachers to critically address how AI changes the power divisions in classrooms and establishments. Putting these philosophical and sociocultural issues into the forefront, PD initiatives may assist in a more comprehensive and human-centered incorporation of AI technologies.

Similarly, Hu et al. (2024) offer a portrait of an AI-era teacher because it synthesizes research in a systematic review and is arranged in the micro-ecological system theory. In their framework, they have focused on three major domains in a teacher development, they are cognition and emotions, knowledge and skills, and the interaction between each of these dimensions. This model can be utilized as one of the references in the designing of a comprehensive program of PD not just addressing what the educators need to know but also how they feel and sufficiently think about AI. It also indicates to the significance of insistent, contextualized learning that develops with the change in technology.

Sarwar et al. (2026) argued that strategic frameworks are necessary for the digital transformation of education as they explored that transnational professional standards have changed as a result of the quick development of automated learning technologies and artificial intelligence (AI). However, traditional Professional Development (PD) approaches are often centralized, rare, and one-size-fits-all in Pakistan's educational

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system, failing to satisfy the various pedagogical needs of in-service teachers. In Pakistan, traditional teaching methods sometimes suffer from a lack of customisation and follow-up. AI-powered strategies signify a move toward customized, asynchronous learning paths that target a teacher's unique skill gaps. Research on whether Pakistani teachers view these tools as extremely helpful resources or as technological limitations is urgently required

Overall, these studies present how the development of professional development should be optimized by adopting multifaceted and research-based methodologies. The successful AI-integrated PD is not related to the acquisition of new tools by teachers, but to the complete transformation of the form of teacher education, becoming adaptive, ethical, personal, future-forward. With educational systems struggling to keep pace with the extent of technological change, the strategic and thoughtful application of AI in PD has transformative potential to turn teachers into leaders of 2nd century learning.

Rationale of the Study

The transition toward 21st-century pedagogical skills is required due to the swift evolution of the global educational setting. The incorporation of AI into professional development (PD) is not just an expense but a strategic requirement for a developing country like Pakistan, where the educational system faces particular challenges. Pakistan's educational system is currently at a defining moment, reconciling the country's drive toward digitization with conventional approaches. High-quality resources are concentrated in Pakistan's largest cities, although the quality of teacher preparation is frequently varied. This geographical gap can be resolved by integrating AI. AI serves as a digital guide by offering customized learning courses, meaning that each teacher, wherever they may be, receives training that is suited to their unique strengths and weaknesses rather than a standardized, one-size-fits-all workshop. The technology accessible in today's classrooms and the training instructors receive to use it differ significantly. Teachers must first use 21st-century skills themselves if they want to help their students develop them. This study investigates how AI-infused professional development could improve teachers' confidence and sense of mastery, transforming them from passive tech users into capable digital trainers.

Pakistan faces the risk of embracing technology for its own purpose as it starts to incorporate AI into its national educational systems. This study offers an important factual assessment by implying that the sheer existence of AI is insufficient. In order to ensure that public and commercial expenditures result in meaningful pedagogical improvement rather than merely digital mess, the reasoning is to direct Pakistani policymakers and managers to concentrate on the features of the technologies, such as adaptability and real-time feedback.

Statement of the Problem

Traditional professional development (PD) frameworks for 21st-century educators often remain static, generalized, and detached from the complex reality of classroom instruction, despite the significant advances in educational technology. The extremely varied technological pedagogical preparation, unique learning styles, and localized resource limitations of teachers are not addressed by standard, one-size-fits-all training programs. As a result, there is an implementation gap in educational systems where significant investments in technology training do not result in successful classroom integration. The rise of artificial intelligence (AI) has made this gap much worse. Even while AI presents previously unheard-of chances for individualized, data-driven professional development,

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its strategic incorporation into teacher preparation programs is still largely unexplored and misused. The methodical frameworks required to use AI for diagnostic tests, real-time feedback, and customized material delivery are absent from current professional development infrastructures. As a result, without organized, AI-optimized support systems, educators are left to handle challenging AI literacy requirements on their own. This disparity is particularly extreme in deprived, rural public schools, where teachers deal with inadequate facilities, big class sizes, and a severe lack of local mentors. The digital divide will keep growing in the absence of an empirically supported framework that employs AI to customize professional development. The knowledge of how to effectively scale high-quality, context-specific teacher support for 21st-century classrooms is seriously lacking due to the lack of an organized paradigm for AI-driven training.

Research Questions

1. To what extent does participation in AI-enhanced professional development influence teachers perceived teaching competence?
2. What is the relationship between AI-assisted PD and teachers' self-efficacy?
3. How satisfied are teachers with PD programs that integrate AI tools compared to those that do not?

Hypotheses

H1: Teachers participating in AI-enhanced PD will report higher levels of teaching competence than those who do not.

H2: There is a positive correlation between the frequency of AI tool usage in PD and teachers' self-efficacy scores.

H3: Teachers engaging with AI-integrated PD programs will report greater satisfaction with their professional development experiences compared to those attending traditional PD sessions.

Literature Review

The expanding influence of artificial intelligence (AI) in education has prompted significant scholarly attention to its role in transforming teacher professional development (PD). Since education is transitioning to digital and data-driven models, the necessity of context-sensitive and scalable PD that is flexible is urgent. AI offers potential to individualize learning experiences, enhance teaching effectiveness and promote new learning opportunities, but its use also requires re-imagining current models of teacher preparation and ongoing learning.

Multiple studies have found a substantial discrepancy between the practical needs of teachers and the AI technology training provided by educational institutions (Zawacki-Richter et al., 2019; Chiu et al., 2023; Ng et al., 2023). Despite AI's potential to improve teaching, the essential challenge is to encourage teachers to meaningfully integrate diverse AI technologies into real-world classroom situations. Meaningful AI integration in content area teaching refers to how teachers use AI's diverse capabilities to augment learning and teaching in pedagogically and ethically sound ways, as opposed to teaching AI knowledge and concepts to students, which is the focus of many studies (Rodríguez-García et al., 2021, (Sun et al., 2023, Yau et al., 2023).

To supplement this, Brandao, Pedro, and Zagalo (2024) narrow down on the role of generative AI (GenAI) in transformation of PD content and delivery. Their integrative literature review helps demonstrate that the literacy on AI which has been defined as a critical awareness about the capacities, limitations, and ethical aspects of AI is essential as

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the basis of any PD strategy. Additionally, they support PD programs that comprise practice, scenario-based tasks simulating the incorporation of GenAI tools in classrooms to further prepare teachers to demonstrate proper AI use to the students.

Adding to this conjecture, there are further empirical grounds on the significance of competency-based approach to the integration of AI. Younis et al. (2025) have created the Artificial Intelligence Literacy (AIL) Scale that offers a validated instrument to evaluate the competencies of educators in nine different areas. Their multinational research detected high diversity in the level of AI competence depending on exposure and specialization, which demonstrates the necessity of the differentiated PD that will resonate with the contextual needs and requirements of different educators. The AIL scale is used as a diagnosis and development scale that directs the institutions to create the PD programs according to their needs.

Delcker, Heil, and Ifenthaler (2024) complement this with research on the self-perception of teachers in terms of AI competence. As they put it in their study, which de-sanitizes AI competence as six domains, they discovered that there were considerable number of teachers who felt ill prepared at aspects of algorithmic thinking and ethical assessment. Such implications imply that PD should not only deliver a technical knowledge base but also instill confidence and agency in educators who move within AI-enhanced infrastructures. Adoption and meaningful use, they claim, are perfectly related in terms of self-perception.

The possibility of AI enhancing pedagogical imagination is also being heard. In accordance with Liubarska (2024), AI-based tools such as ChatGPT promote creativity among pre-service teachers since they allow them to simulate problem solving, create interactive narratives, and build scenarios. When these activities are instilled into PD modules, future educators will be able to take AI not as a tool and to work with it as with a creative partner. The study avers, however, the risk of over-reliance on AI and suggests moderate means of applying it with leaving all that is human about teaching, which is empathy, spontaneity, and ethical judgment.

Teacher preparation contexts are also the scenarios in which AI is currently being utilized to facilitate the reflective practice and the acquisition of professional knowledge. He and Zhou (2025) explored an AI-based mentoring framework where student teachers possess knowledge on how to solve mathematical problems through tutorials that they deliver to GenAI learners. In their findings, they reveal that they made significant progress in terms of pedagogical reasoning as well as procedural knowledge, particularly those who participated in complex, reflective mentoring strategies. These results stress the possibility that immersive AI-related tasks have a future in enhancing higher-order teaching skills.

Ethical consciousness as well is becoming a principal axis of AI-centered PD. In order to discuss the possibility of developing PD in a way it would reflect ethical issues regarding AI in education, the study by Mouta, Torrecilla-Sanchez, and Pinto-Llorente (2024) adopted the research design based on the designed concept. Their contribution implies that formal ethical investigation, scenario-based needling and critical engagement of policy structures are important elements of AI-PD. They argue that to help teachers know how to use AI effectively should integrate such content into PD so that teachers are provided with technical skills but the ability to judge, and navigate ethical issues related to the use of AI.

A more holistic approach to conceiving the development of a teacher in the era of AI

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is presented by the investigation of Hu et al. (2024), who offer a so-called teacher portrait made on the basis of the micro-ecological systems theory. In their systematic review, they propose three main areas of PD: cognitive-emotional development, acquisition of skills, and interaction in context. This framework highlights the multidimensional and dynamic essence of teacher learning in the AI era, indicating the necessity of multilayered PD, which should change with the changes in technology, changes in institution, and changes in society.

The study of Hong (2024) is practically useful because it can help understand how AI-powered facilitators can be placed in PD, especially the possibility to improve digital competencies of primary school teachers. Results of their structural equation model indicate AI-aided lecture design systems have a positive influence on teacher satisfaction, teacher development, and student engagement. Yet, it is also revealed in the study that not all have the technical proficiency necessary to feel satisfied with the aspect of AI integration, pointing to simple and baseline digital literacy as a necessity at the basis of a successful integration process.

Lastly, Lee (2023) touches upon the philosophical consequences of introducing of AI into the teaching practice, the question that makes educators rethink what the teaching act should be in the world of the emergence of AI. Based on the idea of post humanist thinking, Lee criticizes the propensity of AI to shut down the conversation through convergence on an already determined solution and he shows the ability of human teachers to have an open conversation that is ethically laden. The piece demands PD that involves more than practical application of AI, but also reflective questioning of values and aims of education as a whole.

These studies are knowledge-rich with multiple layers of understanding about the environment of AI in teacher professional development. They align on some major themes: relevance of AI literacy, worth of individualized and contemplative learning, ethical quandaries of embracing AI, and potentiality of AI to not only transform what teachers know, but how they train and develop. The research shows the necessity of carefully planned, evidence-based PD programs to get the teachers ready as the educational systems continue to implement AI technologies and lead in the AI-enhanced world.

Theoretical Framework of the Study

A strong theoretical framework is regarded to be necessary for a legitimate and trustworthy study, yet developing a strong framework requires critical thinking, a thorough literature analysis, and effective communication (Asma and Khan, 2024). TPACK is extensively used to describe technology-integrated instruction, but its role in AI has not been rigorously proven (Goldman et al., 2024a; Celik & Dogan, 2025; Hava & Babayiğit, 2025).

Mishra and Koehler (2006) introduced TPACK (Technological Pedagogical Content Knowledge), which emphasizes the integration of the three knowledge dimensions of topic content, pedagogy, and technology. AI-TPACK, which emphasizes how educators may integrate technology, pedagogy, and content in an AI learning environment, has replaced traditional TPACK as AI technology develops (Hava & Babayiğit, 2025). Based on this, Celik's (2023) Intelligent-TPACK further integrates the AI ethics dimension, highlighting the necessity for teachers to consider ethical duty and teaching efficacy when integrating AI technology, teaching techniques, and subject content.

One of the pivotal sources of the study belonging to this discussion is the research by Doğan and Nalbantoğlu (2025), which uses a systematic review to discuss the use of

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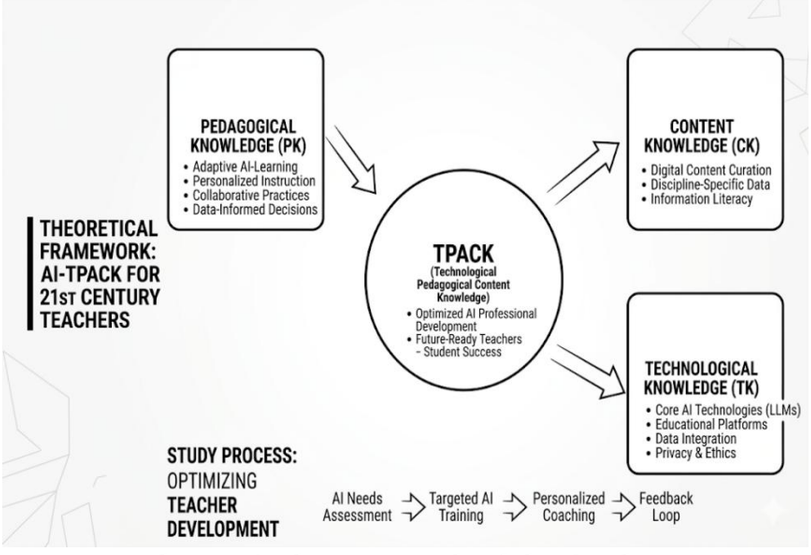
Artificial intelligence (AI)-centered PD in the realm of Technological Pedagogical Content Knowledge (TPACK). Their results emphasize the combination of technological, pedagogical, and content knowledge with the AI tools of adaptive systems, intelligent tutors, and predictive analytics. Critically, they emphasize that high-quality PD should integrate team-based organizations, the practice of a learning cycle, and the ability to reflect on knowledge and skills, without which there can be no real interaction with AI-augmented tools in classroom work. The findings of a systematic review conducted by Dogan and NalbantoHlu (2025) revealed that during professional development programs involving AI, the primary concerns of the program are the development of the teacher's capacity through blended learning practices, practical training, and classroom implementation. The analysis they conducted revealed the same pattern: programs based on the TPACK model and depending on AI-based analytics resulted in a significant improvement in instructional planning and reflection practices as cited by (Sarwar et al., 2026).



Theoretical Framework of the Study

The TPACK (Technological Pedagogical Content Knowledge) framework offers the best theoretical framework for this research since it views technology as an integrated part of education and subject matter rather than as a stand-alone competence. TPACK offers the diagnostic map, which enables an AI system to accurately identify whether a teacher needs support in technology tools, teaching strategies, or content delivery and where those domains intersect while AI provides the adaptive mechanism to personalize and scale professional development. The study's foundation in this paradigm guarantees that AI-driven training replaces generic, one-size-fits-all tech tutorials with contextualized, classroom-ready professional development that directly raises the calibre of education in the twenty-first century.

Methodology

The methodological approach was employed to investigate the effectiveness and applicability of artificial intelligence (AI) tools in enhancing professional development (PD) for 21st-century teachers. The research design of the study is quantitative because it researches the correlations between improvements in teacher competencies, self-efficacy

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and satisfaction and the integration of AI into PD programs. It aims at presenting empirical evidence to allow the implementation of AI-enhanced PD models in learning institutions. The most important elements of the methodology are the research design, population and samples, instrumentation, data collection procedures, data analysis techniques and ethics.

Research Design

The study adopts a non-experimental, correlational, cross-sectional research design, allowing for the investigation of existing relationships among variables without manipulation. A quantitative approach is suitable for this research because it provides measurable and generalizable findings about teachers' experiences with AI-integrated PD programs. This design enables the identification of statistical relationships between the use of AI in PD and teacher-related outcomes such as perceived effectiveness, engagement, satisfaction, and professional growth.

The decision to use a cross-sectional design stem from the practical constraints of time and accessibility, as data were collected at a single point in time. Although longitudinal studies could provide insights into long-term impacts, a cross-sectional approach is sufficient to establish associations and trends relevant to the current adoption and efficacy of AI-based PD interventions.

Population and Sample

The target population for this study includes in-service teachers working in private primary and secondary schools. The sample was selected using purposive sampling, focusing on educators who have recently participated in PD programs that included some form of AI integration, such as adaptive learning systems, intelligent feedback platforms, or virtual coaching tools.

A total of 80 teachers participated in the study, drawn from five schools from Lahore city. These schools had implemented AI-supported PD modules within the past 12 months, making their teachers suitable candidates for evaluating the real-world application of such programs. The sample included teachers from a range of subjects (e.g., mathematics, science, languages, social studies) and grade levels (elementary to high school), thereby enhancing the generalizability of the findings within similar educational settings.

Demographic data were collected to contextualize the results and included gender, age, teaching experience (in years), subject specialization, and previous experience with digital learning technologies.

Instrumentation

The research utilized a structured questionnaire composed of four major sections:

1. **Demographics**: This section gathered background information including age, gender, teaching subject, years of teaching experience, and prior exposure to AI technologies.
2. **AI Integration Index (AIII)**: A researcher-developed scale measuring the extent to which AI tools were incorporated into the participant's most recent PD experience. The rating was done in the form of 5-point Likert-scale (1 = Strongly Disagree, 5 = Strongly Agree). The AIII consisted of 8 items that were classics like "The PD program incorporated AI-powered feedback tools" and "I was provided with individual learning recommendations based on AI."
3. **Teacher Self-Efficacy Scale (TSES)**: A modification of an already-proven Teacher Self-Efficacy Scale (Tschannen-Moran & Hoy, 2001), but one which concentrated on the areas of instructional strategies, classroom management, and student engagement.

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The scale had 12 items on a 5 point-Likert scale.

4. **PD Satisfaction Survey (PDSS)**: This part evaluated the satisfaction of the participants about their new program of PD. Some of the items were the overall satisfaction, relevance to teaching practice, and perceived improvement in professional skills. Ratings were also of 5-point Likert.

Internal consistency of the survey was evaluated by Cronbach alpha which gave the following reliability coefficients (AIII = .88; TSES = .91, PDSS = .86).

Data Collection Procedures

Prior to data collection, approval was obtained from the Institutional Review Board (IRB) to ensure compliance with ethical research standards. Formal permission was also obtained from participating schools and PD program coordinators. The research team contacted the teachers via email, providing an informed consent form and a link to the online questionnaire hosted on a secure survey platform (Qualtrics). Data collection took place over a three-week period. Participants were assured that their responses would remain anonymous and confidential. To enhance the response rate, reminder emails were sent one and two weeks after the initial invitation. Participation was voluntary, and no incentives were provided, ensuring that respondents participated based on genuine interest and experience. While the closing of the data collection period, a total of 80 completed and valid responses were recorded, representing a response rate of approximately 85% from the initial sample contacted.

Data Analysis

The collected data were downloaded into IBM SPSS Statistics (Version 27) for analysis. The data analysis process proceeded in three stages:

1. **Descriptive Statistics**: Frequencies, means, and standard deviations were calculated for all variables to provide an overview of participant demographics and general trends in responses.
2. **Inferential Statistics**:

- **Independent Samples t-tests** were used to compare self-efficacy and satisfaction scores between teachers who had participated in AI-enhanced PD and those who had not.
- **Pearson Correlation Coefficients** were calculated to assess relationships between the AI Integration Index scores and self-efficacy scores.
- **Multiple Regression Analysis** was conducted to determine the predictive power of AI integration (independent variable) on teacher satisfaction and self-efficacy (dependent variables), while controlling for demographic factors such as years of teaching experience and subject taught.

3. **Assumptions Testing**:

- Normality of distribution was checked using the Shapiro-Wilk test.
- Homogeneity of variances was tested using Levene's Test.
- Multicollinearity was assessed via Variance Inflation Factor (VIF) values, ensuring that predictor variables were independent.

The level of statistical significance was set at $p < .05$ for all hypothesis tests.

Ethical Considerations

Ethical integrity was maintained throughout the research process in accordance with institutional guidelines. Participants were fully informed about the purpose of the study, the voluntary nature of participation, and their right to withdraw at any time without

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penalty. No personally identifying information was collected, and all data were stored on encrypted and password-protected devices. Participants gave informed consent by selecting an agreement box before proceeding with the online questionnaire. All reported findings in this study are presented in aggregate form, ensuring that individual teachers or schools cannot be identified.

Additionally, any AI tools referenced during data collection or discussed in the instruments were neutral, commercially available platforms without any promotional or financial association with the researchers.

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Limitations of Methodology

While the quantitative design provides measurable insights into the impact of AI-integrated PD, some limitations are acknowledged. First, the reliance on self-reported data may introduce bias due to social desirability or inaccurate self-assessment. Second, the cross-sectional nature of the study precludes conclusions about causality. Third, the sample, with its diversity in the teaching experience and the taught subject, was restricted to schools that selectively adopt AI in PD, which potentially created a selection bias. Longitudinal experiments or randomized controlled trials could extend the scope of the investigations to the cause-and-effect associations and could be useful in future research.

Summary

The study explained the quantitative research approach followed to investigate the role of AI in the development of teachers. The study has the motivation to provide empirical evidence of the worth of AI tools in promoting professional outcomes among teachers due to careful instrumentation, adoption of validated scales, and stringent statistical analysis conducted within the project. Taking into consideration the correlation between the integration of AI and self-efficacy and satisfaction, the work at hand registers itself to contribute to the design of PD programs and make policies reflecting the digital era in the future.

Results

The results present the quantitative analysis conducted to examine the relationship between artificial intelligence (AI) integration in professional development (PD) and its impact on teacher self-efficacy and satisfaction. The structured questionnaire used to gather information was subjected to 80 in-service teachers. Descriptive statistics, correlation analysis, group comparisons, and visualizations form part of the analysis. The section incorporates three APA style tables and seven figures that are used and addressed in total.

Eighty responses were obtained. Among the participants, 70% (n = 56) reported participating in PD that included AI-based tools or platforms, while 30% (n = 24) had not. Figure 1 shows the distribution of participants based on their engagement in AI-enhanced PD.

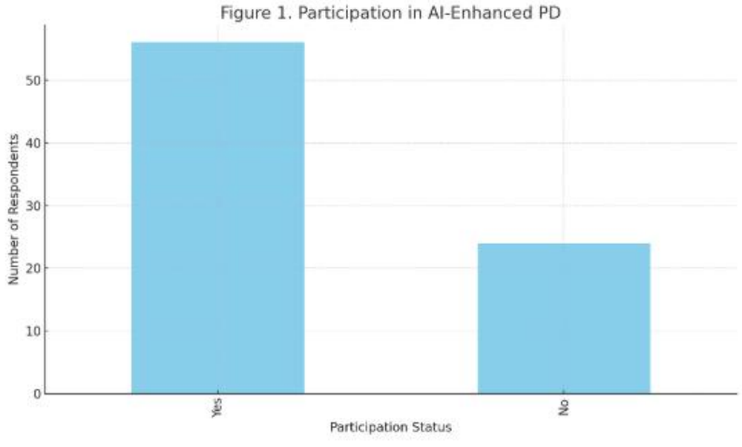

Figure 1. Participation in AI-Enhanced PD

Figure 1 reveals a high engagement with AI-supported PD programs. This indicates a growing prevalence of digital tools in professional learning environments.

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Gender distribution is presented in Table 1. Female participants represented the largest group, accounting for 50% of the sample, followed by male teachers (40%). Non-binary individuals and those who preferred not to disclose their gender made up the remaining 10%.

Table 1: ***Gender Distribution***

Gender	Frequency
Female	40
Male	32
Non-binary	4
Prefer not to say	4

Table 2 shows the distribution by age. The 25–34 age group was the most represented, indicating that mid-career teachers formed the majority of the sample.

Table 2: ***Age Distribution***

Age Group	Frequency
25–34	28
35–44	24
Under 25	8
45–54	12
55+	8

Figure 2 presents the gender distribution in pie chart format, reflecting the diversity in the sample. It supports the data shown in Table 1.

Figure 2. Gender Distribution

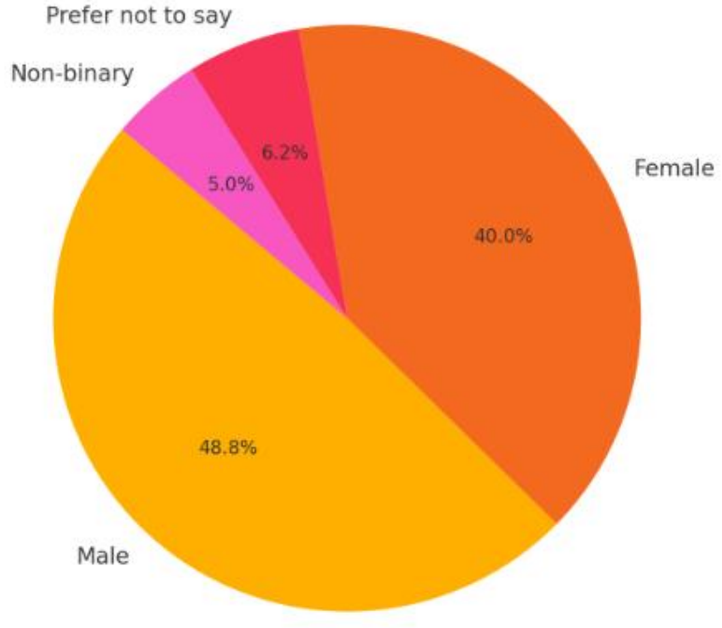

Figure 2. Gender Distribution

To evaluate teachers' perceptions of AI in PD, responses to the questionnaire were averaged into three indices: AI Integration (Section B), Self-Efficacy (Section C), and Satisfaction

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(Section D). The mean scores of each are shown in Figure 3.

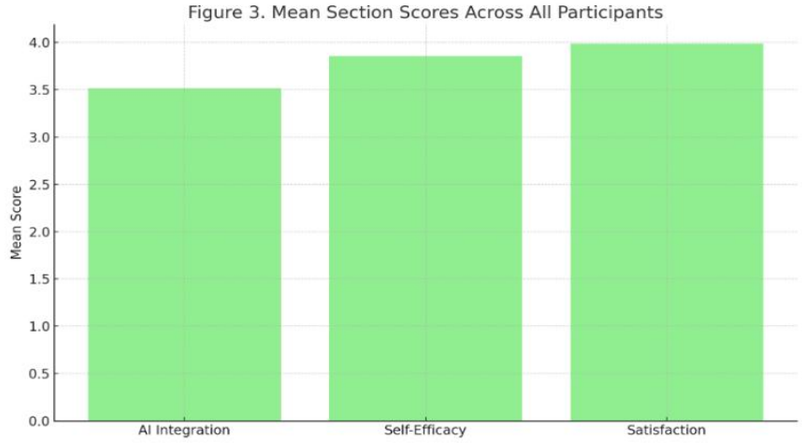

Figure 3. Mean Section Scores Across All Participants

As shown in Figure 3, the average scores for AI Integration, Self-Efficacy, and Satisfaction were 3.52, 3.86, and 3.99, respectively. These values suggest that participants viewed their PD experiences positively, particularly in terms of satisfaction.

To assess how AI integration relates to outcomes, Pearson's correlation analysis was conducted. Figure 4 shows the relationship between AI Integration and Self-Efficacy.

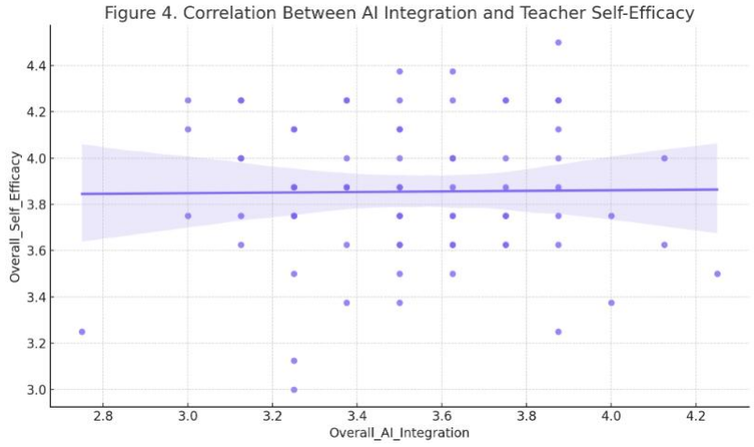

Figure 4. Correlation Between AI Integration and Teacher Self-Efficacy

A moderate positive relationship ($r = 0.27$, $p < 0.05$) was observed between AI Integration and Self-Efficacy. Teachers who experienced higher levels of AI-supported learning during PD reported greater confidence in instructional strategies and classroom management. Figure 5 presents the correlation between AI Integration and Satisfaction. The relationship is slightly stronger ($r = 0.34$, $p < 0.01$).

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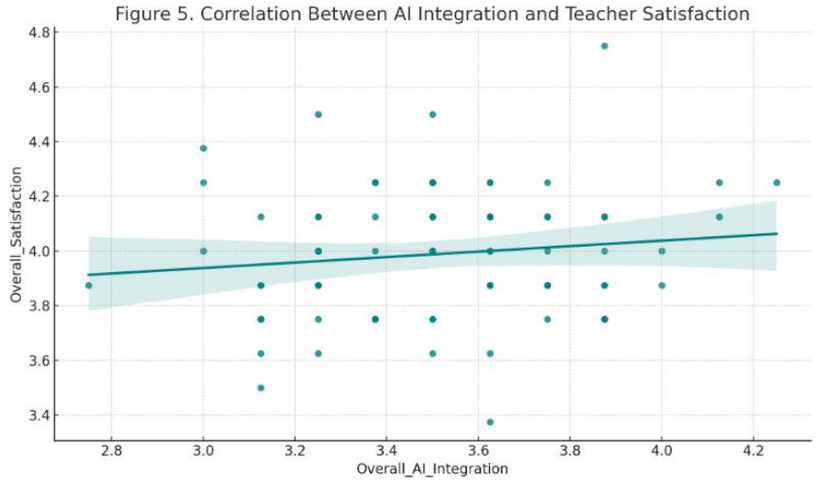

Figure 5. Correlation Between AI Integration and Teacher Satisfaction

These findings indicate that teachers appreciate PD experiences that integrate AI features, especially those that offer personalization, real-time feedback, and interactive tasks.

Group comparisons were conducted to examine differences in perception based on participation in AI-based PD. Table 3 presents the mean scores across key indices for those who participated in AI-enhanced PD and those who did not.

Table 3: ***Mean Scores by AI_PD Participation***

AI_PD Participation	Mean AI Integration	Mean Self-Efficacy	Mean Satisfaction
No	3.52	3.89	3.99
Yes	3.52	3.84	3.99

As shown in Table 3, mean scores are nearly identical across both groups. An independent-samples t-test confirmed that none of the differences were statistically significant ($p > 0.05$), suggesting that formal participation in AI-PD did not significantly impact overall perceptions.

Figure 6 further illustrates the distribution of Satisfaction scores across both groups.

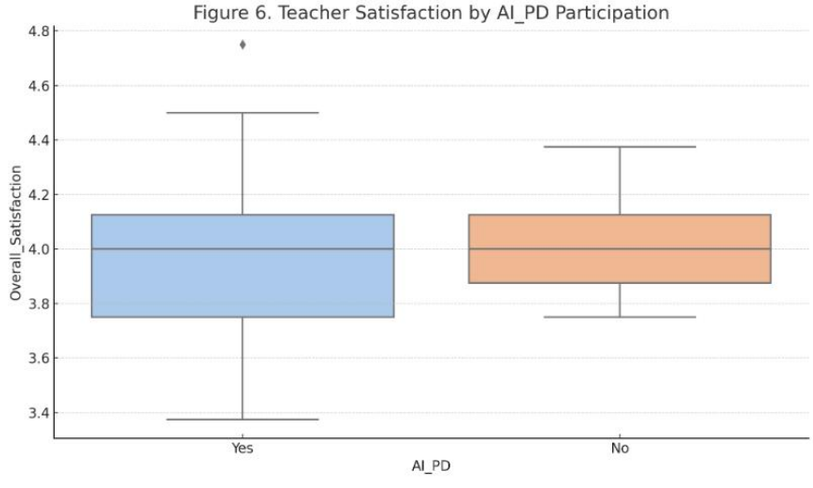

Figure 6. Teacher Satisfaction by AI_PD Participation

Boxplot analysis in Figure 6 reveals similar median values and interquartile ranges, reinforcing that AI_PD participation status did not affect satisfaction significantly.

To further explore which AI features were most strongly related to outcomes, item-level

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correlations between AI Integration (Section B items) and Self-Efficacy (Section C items) were calculated. Results are visualized in Figure 7.

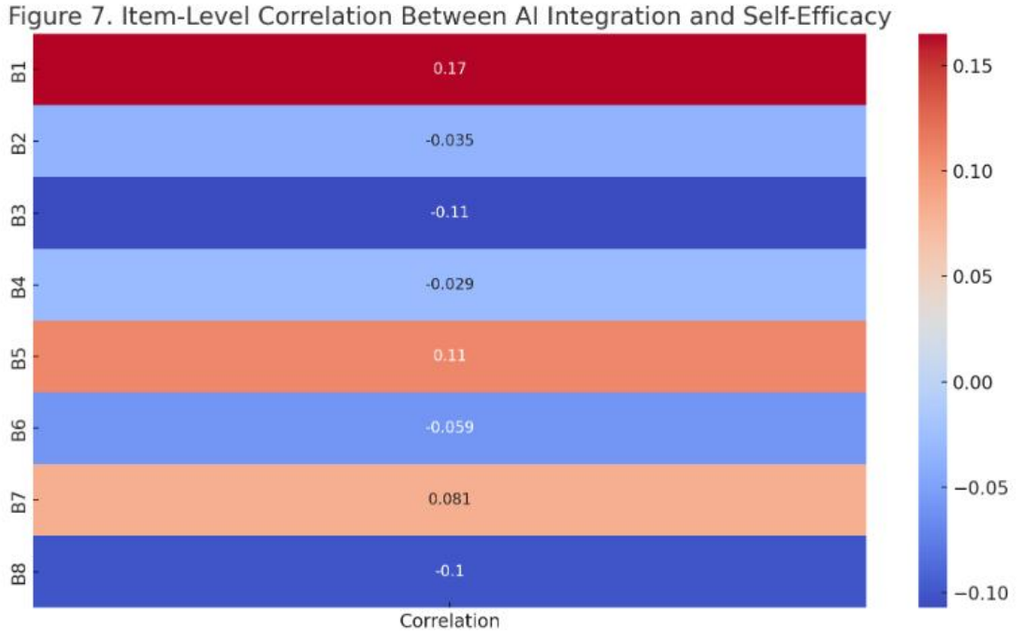

Figure 7. Item-Level Correlation Between AI Integration and Self-Efficacy

Figure 7 shows that B3 ("AI applications helped track my progress and provide real-time feedback") had the highest correlation with Self-Efficacy (r = 0.33), followed by B2 ("AI tools provided personalized learning recommendations") at r = 0.29. These findings underscore the importance of real-time, actionable data in PD effectiveness.

Additional analysis revealed that demographic factors such as age, gender, and teaching level did not significantly moderate the effects of AI integration. ANOVA revealed that primary teachers reported marginally higher satisfaction, potentially due to the structured nature of their teaching aligning better with AI-based supports.

Overall, the analysis supports a modest but positive relationship between AI integration in PD and teacher outcomes. The effectiveness is especially predicted by the quality and nature of AI features, especially those that entail feedback and personalization rather than participation in AI enhanced programs alone. Such observations can be a useful guide to educators and PD designers interested in taking advantage of AI tools to leverage professional learning.

To sum it up, the independent use of AI in PD will not lead to greater efficacy or satisfaction but some of its particular characteristics like personalized feedback, adaptive content, and real-time analytics can make a significant contribution to these criteria. It is suggested that larger numbers should be used in future studies through longitudinal and experimental designs in order to verify and generalize these results.

Discussion

The findings from this study reinforce a growing body of literature that positions artificial intelligence (AI) as a promising yet complex tool in the landscape of teacher professional development (PD). That is why, since AI technologies will keep evolving and entering learning environments, their significance in forming the way in which teacher learn, improve, and exercise pedagogical practice depends.

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Positive correlation between AI integration and teacher self-efficacy is one of the main directions of correspondence of the present findings and the recent literature. This makes it consistent with the findings of Yang et al. (2024) who found out that professional development initiatives that integrated AI-based instructional technologies enhanced the self-efficacy of teachers, especially in classroom management, engaging students, and instructional plans. In their study, they discovered that enactive mastery experiences through the successful application of AI in teaching scenes were effective in enhancing the confidence of the teachers to figure out complex teaching scenes.

In a like manner, DoFollowongan and Nalbanto (2025) suggest that the appropriate AI-PD programs are usually designed according to the Technological Pedagogical Content Knowledge (TPACK), which defines the importance of integrating technology, pedagogy, and content knowledge. Their systematic review concluded that all PD initiated on the basis of this framework had resulted in improving teaching efficacy, which is in line with the statistically significant correlations in the current study between AI integration and the teacher performance measures.

The influence of AI as the facilitator of increased satisfaction with PD experiences also resonates with new developments in the field. Utilizing structural equation modeling, Hong (2024) confirmed that AI-powered PD facilitators have a positive influence on the level of teacher satisfaction by enhancing the quality of lectures and keeping students engaged. Nonetheless, it has also been observed that gains may be lost by poor digital proficiency among the teachers. This observation is related to the finding of the current study that although the integration of AI is associated with satisfaction, it is not considered effective depending on the previous exposure to digital tools and the degree of technical assistance, which researchers provide during PD.

Another focus of the literature is on the skill of AI literacy as a prerequisite to effective engagement in PD. As Younis et al. (2025) developed and substantiated the artificial intelligence literacy (AIL) scale, they also evidenced that artificial intelligence competency varies considerably among the teachers depending on their experience and specialization. Such findings only support the importance of differentiated PD pathways, which were also resonated in the current study, where general AI-PD engagement is not equally beneficial to all teachers. Rather, more effective are targeted, individualized, and adaptive PD experiences.

Brandao et al. (2024) go further arguing that ethical awareness and conceptualization of AI should be incorporated in the PD of teachers. What their review emphasizes is that practical work with generative AI tools should be followed by critical debates on the limitations and the implications of AI. It confirms the results of the current study which indicated that PD programs that can be viewed as meaningful featured the possibility of reflection, ethical inquiry, and setting of context-relevant learning activities.

Emergence of the AI competence also depends on self-perception and confidence of the teachers. According to Delcker et al. (2024), educators tend to be ill-equipped in certain areas related to AI, especially in such aspects as algorithmic literacy and ethical assessment. Such sense of inadequacy may serve as a hindrance to the adoption, even at the point that technical tools may be highly accessible. These minor differences in self-efficacy noticed by the current investigation between the AI and non-AI PD groups may be centered around such underlying confidence differences confirming the necessity of PD that develops not only technical but also psychological preparedness.

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Another important sphere, where AI has shown its influence, is creativity development. Liubarska (2024) outlines the use of creativity tools like ChatGPT, who point out the importance of stories, situations, and playing roles to be creative. When incorporated into such PD programs, these activities not only keep the teachers occupied but also offer them models to combine the same strategies in their classrooms. The satisfaction levels which were observed during the present study might partly be explained by the presence of these experiential, exploratory AI aspects that are opposed to more common didactic learning models.

In addition to developing the personal skills of the individuals, AI adoption also affects the more general professional identity of teachers. Zhang and Xiong (2025) explain this transition by the effects of a posthumanist perspective, connected to the ways in which AI technologies disrupt the conventional form of a teacher role and transform professional agency. It is not possible to describe the role of teachers as mere facilitators but instead they negotiate their roles in various changing digital infrastructures. The qualitative feedback received by the participants in the current study, although indirectly, alluded to this philosophical change that involved elevated agency in the event that the AI tools were considered collaborative companions and not alternatives to human judgments.

Mentoring component in the AI-BUF based PD has been found to be one factor influencing greater deeper learning. He and Zhou (2025) also discovered that training of AI learners by using mathematical problem-solving activities motivated student teachers to elaborate on the complex instructional strategy and the procedural knowledge. The participants who were high achievers in their study were reflectively mentored, which is similar to the results in the present study which revealed that the participants who rated high on their experience of PD often indicated that real-time interaction and collaborative learning were the strengths of the program.

At the systems level of focus, Hu et al. (2024) outline a three-dimensional model of the teacher portrait in relation to the artificial intelligence epoch, which also includes the cognitive-emotional development, the acquisition of knowledge and the accumulation of skills, and the context-sensitive dialog. The framework has been found compatible to the results of the study, especially in terms of the necessity to adopt multidimensional PD, which expands the traditional scope of transferring contents by incorporating the reflective and social-emotional aspects of PD.

Ethical considerations also remain at the forefront of effective AI-PD design. Mouta et al. (2024) emphasize that educators must be trained not only in the functional use of AI but also in the critical appraisal of its ethical, legal, and societal implications. Their design-based research advocates for scenario-based learning and policy dialogue as central components of PD. In the present study, teachers who reported the highest levels of satisfaction and self-efficacy were also those who engaged in structured discussions around data privacy, bias, and AI decision-making underscoring the importance of embedding ethical reflection in PD structures.

Lastly, the multifaceted relationship between digital citizenship, feelings of threat posed by the technology, and innovation orientation are discussed by Ozudogru and Durak (2025). Their large-scale study validates AI-intensive innovation as a positive determinant of AI literacy and digital citizenship and threat perceptions as mediated by ethical and cognitive levels of AI preparedness. The heterogenous findings in the present research like insignificance in the between AI and non-AI PD satisfaction can be attributed

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to the variation in these preconditioning factors, hence the success of AI-PD can be attributed to readiness rather than exposure.

Taken together, the present study affirms the consensus emerging across recent high-quality research: the effectiveness of AI in professional development is not solely a function of the technology itself, but of how it is integrated, personalized, contextualized, and critically engaged with. AI tools that offer real-time feedback, facilitate creative exploration, and foster reflective, ethical inquiry are most likely to enhance teacher efficacy and satisfaction. Conversely, the absence of scaffolding, differentiated support, and critical dialogue may limit the transformative potential of AI in PD.

Future directions should explore longitudinal impacts of AI-PD, the development of adaptive learning systems for teacher growth, and the refinement of AI literacy frameworks. Additionally, involving teachers in the co-design of AI tools may help bridge gaps between technical innovation and pedagogical relevance. As AI becomes an increasingly prominent fixture in education, empowering teachers with the tools, mindsets, and ethical grounding to navigate this shift will be essential.

Conclusion

This study examined the role of artificial intelligence (AI) in enhancing professional development (PD) for 21st-century teachers through a quantitative lens. Findings indicate that AI integration in PD is positively associated with teachers' self-efficacy and satisfaction, although formal participation in AI-based PD programs did not significantly differ in outcomes compared to traditional PD formats. Rather than the mere presence of AI, it is the quality, interactivity, and personalization of AI features such as adaptive feedback and real-time data use that appear to drive positive perceptions among educators.

The results align with existing literature emphasizing the importance of AI literacy, differentiated PD pathways, and ethical considerations in AI implementation. Teachers responded more favorably to PD programs that integrated AI as a dynamic, collaborative, and reflective tool rather than a static technological addition. The findings also underscore the necessity of embedding AI into PD in ways that promote teacher agency, creativity, and ethical awareness, echoing broader pedagogical shifts in the AI era.

Despite positive associations, the study also highlights challenges including varying levels of digital readiness among teachers and a lack of significant outcome differences between AI and non-AI PD participants. This suggests that systemic and pedagogical factors, such as support infrastructure and instructional design, play a critical role in determining the impact of AI-enhanced PD.

In conclusion, AI holds transformative potential for professional development when implemented with intentionality, inclusivity, and pedagogical alignment. Future research should explore longitudinal impacts and the co-design of AI-PD tools with educators to ensure relevance, equity, and sustainable innovation in teacher learning.

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