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Human–Machine Co-Learning in Teacher Education: Pre-Service Science Teachers' Perceptions of Artificial Intelligence Integration

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Although artificial intelligence integration in higher education has received growing scholarly attention, limited evidence exists on how pre-service science teachers in teacher education institutions perceive AI as part of their future professional practice. Addressing this gap, the present study applies a Human–Machine Co-Learning lens to examine AI not merely as a technological tool, but as a potential instructional partner that may reshape teacher preparation. This study examined pre-service science teachers' awareness, attitudes, and perceived benefits and challenges regarding integrating artificial intelligence (AI) into teacher education through a human–machine co-learning lens. Using a descriptive survey design, 303 undergraduate pre-service teachers in five science education majors at Farhangian University (Tehran) completed a researcher-developed questionnaire (21 items; α=.89). Participants reported relatively high AI awareness (M=7.20/10, SD=1.13) and largely viewed AI as an instructional partner rather than a replacement for teachers (>70%). One-way ANOVA indicated small but significant differences in awareness across majors, F (4,298) =3.20, p=.014, η^2=.041. Key perceived barriers were limited technological infrastructure, insufficient formal training, and ethical/policy ambiguities. Findings suggest that, with targeted training, improved infrastructure, and clear ethical guidance, AI can support instructional design and assessment while preserving the human and professional role of teachers.

Keywords: artificial intelligence, teacher education, human–machine co-learning, pre-service teachers, perceptions of AI

INTRODUCTION

In recent decades, artificial intelligence (AI) has emerged not merely as a technological innovation but as a powerful and transformative force shaping multiple domains of human life, including industry, services, and education. Higher education—and teacher education in particular—has been directly affected by both the opportunities and

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challenges associated with the integration of AI technologies (Zawacki-Richter et al., 2019; Chen et al., 2020). By enabling adaptive learning, content personalisation, learning analytics, and intelligent content generation, AI has begun to reshape teaching and learning practices and to create new possibilities for enhancing educational quality (Slimi, Benayoune, & Alemu, 2025). These affordances are especially salient in data-intensive and conceptually complex disciplines such as the basic sciences.

In this study, *human–machine co-learning* is adopted as a conceptual framework for interpreting the data. Within this framework, AI is understood as an instructional tool and learning partner that complements the teacher rather than replacing them. Operationally, this framework is represented through four dimensions: (1) awareness of AI capabilities and limitations; (2) attitudes and emotional responses toward professional and ethical implications; (3) perceived benefits for instructional design and assessment; and (4) contextual and institutional challenges. Each dimension was measured through corresponding subscales of the questionnaire.

Education, as the core mechanism for developing human capital, depends fundamentally on teachers who are capable of preparing students to navigate rapid technological change. In this context, pre-service teachers' levels of awareness, attitudes, and readiness to engage with AI play a decisive role in shaping the future effectiveness of educational systems. However, the meaningful integration of AI into classroom practice is accompanied by concerns related to ethical implications, the preservation of the teacher's human role, and infrastructural constraints. Consequently, understanding the perspectives of pre-service teachers, as key future stakeholders, has become increasingly important.

Although international studies, including large-scale surveys (e.g., Petrașcu, 2023), have examined university students' general perceptions of AI; however, the Iranian context, and particularly Farhangian University as the national institution responsible for teacher education, presents distinctive structural, cultural, and institutional characteristics that warrant context-sensitive investigation. Three main factors underscore the necessity of such a study.

First, the critical role of teachers requires particular attention. Future teachers must not only possess technological competencies but also be able to integrate AI meaningfully into instructional design, assessment, and pedagogical interaction. Holmes et al. (2019) argue that in the digital era, teachers increasingly assume the role of "learning designers working alongside AI." Similarly, Zawacki-Richter et al. (2019) emphasise the importance of developing both technological and ethical literacy among teachers.

Second, disciplinary specialisation is a key consideration. Pre-service teachers in physics, chemistry, biology, mathematics, and integrated science (STEM-related fields) are particularly well positioned to benefit from AI due to the analytical, model-based, and data-driven nature of their disciplines. Their perceptions of AI applications in scientific simulations, data analysis, and the teaching of abstract concepts therefore carry heightened significance.

Third, local and institutional challenges—including infrastructural limitations, technology-related policies, and context-specific ethical considerations within

Farhangian University—necessitate a locally grounded investigation to capture the realities of AI integration in teacher education.

Accordingly, the central research question guiding this study is as follows: What are the perceptions, levels of awareness, emotional responses, and understandings of the benefits and challenges associated with integrating AI into educational processes and the future role of teachers among male pre-service teachers in science education majors at Faculty of Science Education of Farhangian University?

This study is significant from theoretical, practical, and institutional perspectives. Theoretically, by applying and contextualizing Petrașcu's (2023) international model within Farhangian University, the study contributes to the enrichment of the Iranian educational technology literature and provides comparative data for examining similarities and differences between Iranian pre-service teachers and university students in other contexts. Practically, the findings offer a diagnostic assessment of readiness, knowledge gaps, and attitudinal patterns among pre-service science teachers, informing (a) university administrators in revising curricula with a focus on AI literacy, (b) educational authorities in developing transparent policies regarding appropriate and inappropriate uses of AI, and (c) future teachers in recognising both opportunities (e.g., willingness to use AI) and concerns (e.g., fears of replacement or dehumanization). Institutionally, the focus on Shahid Beheshti Campus as a specialized centre for male students in basic sciences enables the identification of infrastructure needs and policy priorities specific to Farhangian University.

Previous research in higher education consistently suggests that AI functions not as a substitute for teachers but as an educational partner and support system. Tools such as intelligent tutoring systems, automated assessment, AI-based content generation, and personalized AI-supported learning environments have already been adopted in different educational contexts (Luckin et al., 2016; Chen et al., 2020). More recent evidence from the International Journal of Instruction extends this general view by showing that AI can support both subject-specific learning and teacher preparation. Drushlyak et al. (2025) demonstrated that ChatGPT-based simulation can help pre-service mathematics teachers develop critical thinking when they are required to evaluate AI-generated solutions. Similarly, Kemouss and Khaldi (2025) showed that AI-supported instruction can contribute to personalized learning in physics education. These studies suggest that the educational value of AI depends not only on access to AI tools, but also on how these tools are pedagogically structured and critically used by learners and future teachers. Across studies, students typically report moderate to high levels of AI awareness, much of which is acquired through informal sources such as social media and online platforms. Common emotional patterns include curiosity, ethical concern, and anxiety regarding the potential replacement of teachers (Rouhiainen, 2019; Bochniarz et al., 2022; Gessl et al., 2019; Edelman, 2019). Iranian studies similarly highlight the need to strengthen teachers' AI literacy, attend to ethical considerations, and preserve human interaction alongside technological innovation (Mehrpour & Hajizadeh, 2025; Mehrmohammadi, 2025).

Despite this growing body of research, studies that specifically examine pre-service teachers in science education majors while explicitly addressing the infrastructural and

institutional conditions of Farhangian University remain scarce. The novelty of the present study lies in its focus on this specialised population and its contextualised application of Petraşcu's (2023) model within teacher education. By addressing this gap, the study aims to provide evidence-informed insights that can support policy development and strategic planning for AI-integrated teacher education.

Taken together, previous studies consistently demonstrate that AI has considerable potential to enhance teaching and learning and that students generally report positive attitudes toward its educational use. However, three important gaps remain. First, most existing studies have examined general university populations rather than pre-service science teachers whose future professional responsibilities require pedagogically informed AI competencies. Second, limited attention has been given to institutional contexts in developing countries where infrastructural, cultural, and policy conditions substantially influence AI adoption. Third, relatively few studies have interpreted pre-service teachers' perceptions through the Human–Machine Co-Learning perspective, which emphasizes collaborative interaction between teachers and AI rather than technological substitution. Addressing these gaps constitutes the primary theoretical contribution of the present study. In addition, recent work in Anatolian Journal of Education indicates that the educational value of ChatGPT depends strongly on how teachers structure prompts, define goals, assign roles, and set clear boundaries for AI-generated outputs (Dertli & Yıldız, 2025), which further supports the need to examine future teachers' readiness for responsible AI use.

METHOD

Research Design

This study employed a descriptive–analytical survey design with a cross-sectional approach to examine and compare pre-service basic science teachers' perceptions of integrating artificial intelligence (AI) into teacher education.

Population and Sampling

The statistical population comprised all male pre-service teachers enrolled in basic science education programmes (Mathematics Education, Biology Education, Chemistry Education, Integrated Science Education, and Physics Education) at Shahid Beheshti Campus of Farhangian University, Tehran, during the 2025–2026 academic year. According to official records, the total population consisted of 1,435 students (Table 1).

Given differences in enrolment sizes across disciplines and the importance of proportional representation, proportionate stratified sampling was employed. Each academic discipline was treated as a stratum, and the sample size for each stratum was determined based on its proportion within the total population. The required sample size was calculated using Cochran's formula for finite populations, assuming a 95% confidence level and a 5% margin of error, resulting in a minimum sample of 303 participants. To mitigate potential non-response, a target of 310 participants was set, of which 303 valid questionnaires were ultimately analysed (Table 1).

Instrument

Data were collected using a researcher-developed questionnaire administered online. The instrument was designed based on relevant international models, particularly

Petrașcu's (2023) framework, and was contextualised to reflect the characteristics of pre-service teachers in science education majors. The questionnaire consisted of 21 items organised into five main sections:

1. Demographic and contextual information;
2. Awareness of AI and sources of AI-related information;
3. Emotional responses and general attitudes toward the ethical and professional implications of AI;
4. Perceived benefits and applications of AI in teaching and learning basic science subjects;
5. Perceived local and institutional challenges, including infrastructure, access to resources, and university-level policies.

Items assessing attitudes, perceived benefits, and challenges were measured using a five-point Likert scale ranging from *strongly disagree* to *strongly agree*. Items related to AI awareness were measured on a 10-point ordinal scale (1–10).

Validity and Reliability

Content validity was established through expert review. The questionnaire was examined and refined by five experts in educational technology, educational sciences, and teacher education.

Instrument reliability was assessed using Cronbach's alpha coefficients, which indicated satisfactory internal consistency across all dimensions:

- Awareness: $\alpha = 0.81$
- Attitudes and emotions: $\alpha = 0.87$
- Perceived benefits: $\alpha = 0.85$
- Local challenges: $\alpha = 0.88$
- Overall questionnaire: $\alpha = 0.89$

Ethical Considerations

At the beginning of the questionnaire, participants were informed about the purpose of the study, the voluntary nature of participation, their right to withdraw at any time, and the intended use of the data. Completion of the questionnaire was considered to constitute informed consent. No identifying information was collected, and all data were treated as confidential and analysed solely for research purposes.

Data Analysis

Data were analysed using SPSS version 26. In addition to descriptive statistics (means, frequencies, percentages, and standard deviations), one-way analysis of variance (ANOVA) was conducted to compare mean scores across academic disciplines. Effect sizes were reported using *eta squared* (η^2).

FINDINGS

This section presents the findings based on the analysis of 303 valid questionnaires. First, respondents' demographic characteristics are reported, followed by results related to levels of AI awareness, emotions and attitudes, perceived benefits and challenges of AI integration in education, and finally, a comparative analysis across basic science education majors.

Of the 310 questionnaires distributed, 303 were suitable for analysis, yielding a response rate of 97.7%. Of the respondents, 59% were in their second or third year of study, while 41% were first-year students. The disciplinary distribution of the sample closely matched the population structure and included Mathematics Education (25%), Biology Education (24%), Chemistry Education (15%), Integrated Science Education (18%), and Physics Education (17%). In terms of age, 65% of participants were between 20 and 22 years, and 35% were older than 22 years (Table 1). All participants were enrolled in continuous full-time undergraduate programmes.

Table 1
Demographic characteristics of participating pre-service teachers (N = 303)

Variable	Category	Frequency	Percentage
Year of study	First year	124	41%
	Second & third year	179	59%
Discipline	Mathematics Education	76	25%
	Biology Education	74	24%
	Chemistry Education	45	15%
	Integrated Science Education	55	18%
	Physics Education	53	17%
Age	20–22 years	197	65%
	Above 22 years	106	35%
Academic status	Undergraduate student	303	100%

Awareness of Artificial Intelligence

Analysis of items related to AI awareness indicated a mean awareness score of 7.20 out of 10 (SD = 1.13), suggesting a relatively high level of awareness among pre-service basic science teachers.

Regarding sources of AI-related knowledge**,** search engines and internet resources (89%)**,** social media platforms (76%)**,** and discussions with friends or classmates (42%) were indicated as the most common sources. Only 18% of participants indicated that they had participated in a formal university course or workshop related to AI. These findings suggest that, despite generally high awareness levels, informal sources play a dominant role in shaping participants' understanding of AI (Table 2).

Table 2
Indicators of AI awareness

Indicator	Value
Mean AI awareness (out of 10)	7.20
Participation in formal AI training	18%
Main sources of awareness	
– Social media	76%
– Internet search engines	89%
– Friends/classmates	42%

Emotions and Attitudes Toward AI

With respect to emotions and attitudes, 51% of respondents reported feelings of *curiosity and optimism* toward the educational applications of AI. In contrast, 27% expressed *concern or fear regarding the potential weakening of the teacher's human role*, while 22% indicated a neutral attitude. Among specific concerns, reduced human interaction in teaching–learning processes (63%) and overdependence on technology

(58%) were most frequently cited. Conversely, 72% of respondents believed that AI could assist teachers in instructional design and learner assessment (Table 3).

Table 3
Emotions and attitudes toward AI

Attitude/emotion category	Percentage
Curiosity and optimism	51%
Concern/fear of the weakening of the teacher's role	27%
Neutral attitude	22%
Specific concerns	
– Reduced human interaction	63%
– Overdependence on technology	58%
Positive attitude toward educational applications	72%

Perceived Benefits and Applications of AI in Basic Science Education

The findings indicated that 65% of pre-service teachers viewed AI as a *supportive tool and educational partner* rather than a replacement for teachers. Additionally, 59% believed that AI could increase access to personalised educational resources, 54% highlighted its role in promoting active and interactive learning, and 48% pointed to its potential to enhance educational assessment. The mean score for perceived benefits on the five-point Likert scale was 3.96 out of 5**,** reflecting an overall positive perception of AI's instructional functions (Table 4).

Table 4
Perceived benefits and instructional functions of AI

Component	Percentage agreeing
AI as a supportive instructional tool	65%
Increased access to personalised learning	59%
Enhanced active learning	54%
Improved assessment quality	48%
Mean perceived benefits (out of 5)	3.96

Perceived Challenges and Barriers to AI Integration

Analysis of perceived challenges revealed three primary barriers: insufficient technological infrastructure (71%), lack of formal training and digital skills among students and instructors (64%), and ethical and policy-related ambiguities in the use of AI tools (58%). The mean score for perceived challenges on the five-point Likert scale was 4.04 out of 5, indicating a relatively high level of perceived constraints and a strong need for technological capacity-building within the studied context (Table 5).

Table 5
Main perceived challenges and barriers to AI integration

Indicator	Percentage agreeing	Mean (5-point scale)
Overall perceived challenges	—	4.04
Inadequate technological infrastructure	71%	—
Lack of formal training and digital skills	64%	—
Ethical and policy-related ambiguities	58%	—

As shown in Table 5, the reported barriers refer specifically to institutional, instructional, and ethical constraints rather than to perceived instructional benefits, which are presented separately in Table 4.

Comparative Analysis Across Disciplines

Results of the one-way ANOVA indicated a statistically significant difference in AI awareness across science education majors, $F(4, 298) = 3.20$, $p = .014$, $\eta^2 = .041$. However, the effect size was small, suggesting that while differences were statistically significant, their practical significance was limited (Table 6).

Table 6
Comparative analysis of AI awareness across disciplines

Discipline	Mean	SD
Physics Education	7.80	1.05
Mathematics Education	7.40	1.10
Chemistry Education	7.00	1.12
Biology Education	6.90	1.15
Integrated Science Education	6.50	1.18

Summary of Findings

Overall, the findings indicate that pre-service basic science teachers at Farhangian University demonstrate relatively high levels of AI awareness, generally positive attitudes, and a readiness to engage with and utilize AI. At the same time, the absence of formal training, infrastructural limitations, and ethical and professional concerns among future teachers emerged as key barriers to the effective integration of AI into educational processes. These results underscore the importance of strengthening both technological and ethical preparation and of developing clear, context-sensitive, institutional, and human-centered frameworks to support responsible AI use in teacher education.

DISCUSSION

The present study aimed to examine the levels of awareness, attitudes, emotional responses, and perceptions of benefits and challenges related to the integration of artificial intelligence (AI) in educational processes from the perspectives of pre-service science education teachers at Farhangian University, with particular emphasis on the concept of human–machine co-learning. The findings indicate that, despite infrastructural and instructional limitations, these future teachers demonstrate relatively high levels of AI awareness and generally positive attitudes toward its educational applications. This suggests that AI is gradually becoming part of the professional horizon of future teachers, albeit one that remains intertwined with institutional and ethical considerations.

The mean AI awareness score of 7.20 out of 10 indicates that pre-service basic science teachers possess a moderate to high level of familiarity with AI concepts and applications. This finding is consistent with international studies, including Petrașcu (2023) and Slimi, Benayoune, and Alemu (2025), which report similar levels of awareness among higher education students. However, the limited contribution of formal university-based instruction to this awareness suggests that AI-related knowledge is predominantly acquired through informal learning pathways rather than formal instruction. This pattern highlights a structural gap within teacher education programmes and underscores the need to revise curricula with a stronger focus on AI literacy.

In terms of attitudes and emotions, the results reveal a dual tendency. On the one hand, a substantial proportion of pre-service teachers expressed curiosity and optimism toward AI, viewing it as an opportunity to enhance educational processes. On the other hand, concerns were raised regarding the potential weakening of the teacher's human role, reduced face-to-face interaction, and overreliance on technology. Similar ambivalent patterns have been indicated in prior studies (e.g., Edelman, 2019; Gsell et al., 2019), indicating that the adoption of emerging educational technologies is often accompanied by ethical and professional concerns. These findings suggest that while pre-service teachers are open to innovation, they continue to place strong value on the relational and human dimensions of teaching.

The results further indicate that the majority of participants conceptualise AI not as a replacement for teachers but as an educational partner and supportive tool. This pragmatic orientation aligns with contemporary perspectives in the educational literature, particularly those emphasising the complementary role of AI in instructional design, personalised learning, and assessment (Luckin et al., 2016; Kemouss & Khaldi, 2025). Such perceptions reflect a shift away from human–machine competition toward a synergistic human–technology model in line with recent educational paradigms, which resonates with the human–machine co-learning framework adopted in this study.

From a Human–Machine Co-Learning perspective, this finding suggests that pre-service teachers do not perceive AI integration as a process of replacing human pedagogical agency, but as a redistribution of instructional roles between teachers and intelligent technologies. In this sense, AI may support routine, analytical, and resource-generating tasks, while teachers remain responsible for ethical judgment, contextual interpretation, emotional support, and pedagogical decision-making. Therefore, the value of AI in teacher education depends not only on technological availability, but also on preparing future teachers to critically negotiate the boundaries of collaboration between human expertise and machine-generated support. This interpretation is consistent with Drushlyak et al. (2025), who demonstrated that AI-generated responses can be used productively in teacher education when pre-service teachers are guided to evaluate, question, and correct machine outputs rather than accept them uncritically.

At the same time, perceived challenges play a critical role in shaping these attitudes. Inadequate technological infrastructure, insufficient formal training, and ethical and policy-related ambiguities emerged as the most salient barriers. These findings are consistent with previous research highlighting the importance of institutional readiness, clear policies, and ethical frameworks in higher education contexts (Zawacki-Richter et al., 2019; Chen et al., 2020). Within the context of Farhangian University, such challenges may hinder the translation of positive attitudes into effective classroom practices.

These findings also suggest that positive perceptions of AI alone are insufficient to ensure meaningful educational integration. From a Human–Machine Co-Learning perspective, effective collaboration between teachers and AI requires the simultaneous development of technological competence, institutional support, and ethical awareness. Consequently, successful AI implementation should be viewed as a systemic educational process rather than merely the adoption of new digital tools. This

interpretation extends previous research by emphasizing that teacher preparedness depends on the interaction between individual readiness and institutional capacity.

The comparative analysis across science education majors revealed statistically significant differences in AI awareness, with pre-service physics teachers reporting the highest levels. This pattern can be attributed to the analytical and data-intensive nature of physics education. However, the small effect size and the absence of substantial differences in overall attitudes and perceived benefits across disciplines suggest that openness to AI is relatively widespread across disciplines among pre-service basic science teachers. With targeted and discipline-specific training, this general openness could be translated into practical competencies across all subject areas.

Nevertheless, given the small magnitude of the reported effect size ($\eta^2 = 0.041$), differences between disciplines should be interpreted with caution, therefore particularly in terms of their practical significance. To better understand the sources of these differences, future studies should report post-hoc comparisons and examine the role of contextual variables such as year of study and prior experience with digital tools.

Overall, the findings lend support to the human–machine co-learning approach in teacher education. This perspective emphasises the use of AI as a supportive tool that operates alongside teachers' professional judgement, ethical responsibility, and human interaction. The results suggest that the successful integration of AI into teacher education depends less on technological advancement alone and more on the quality of teacher preparation, systematic institutional policymaking, and the development of clear and ethically grounded frameworks. When these conditions are met, AI can function as a valuable and transformative resource for enhancing educational processes and supporting teachers' professional development.

LIMITATIONS

This study has several limitations that should be acknowledged when interpreting the findings. First, the data were self-reported and collected using a cross-sectional survey design, which limits the ability to infer causal relationships. Second, due to the gender-segregated structure of Farhangian University, the study population was restricted to male pre-service teachers, which may limit the generalisability of the findings to other contexts. Future research is encouraged to employ longitudinal or quasi-experimental designs and to include more diverse samples in terms of gender, institutional settings, and geographical regions.

Another limitation concerns the validation of the researcher-developed questionnaire. Although content validity was established through expert review and internal consistency was confirmed using Cronbach's alpha coefficients, further validation procedures such as exploratory or confirmatory factor analysis were not conducted. Future studies should therefore examine the factorial structure of the instrument and report additional validity indices to strengthen the measurement model.

IMPLICATIONS AND RECOMMENDATIONS

Drawing on the findings and informed by the human–machine co-learning approach to teacher education, several implications and recommendations are proposed. The main scientific contribution of this study lies in showing that pre-service science teachers'

readiness for AI integration is shaped not only by their awareness and positive attitudes, but also by the interaction between institutional infrastructure, ethical concerns, and professional conceptions of the teacher's role. By interpreting these findings through the Human–Machine Co-Learning perspective, the study extends current discussions on AI in teacher education from a technology-adoption issue to a broader question of human–AI collaboration in pedagogical practice.

Educational Implications

Teacher education programmes should be revised to ensure that AI-related instruction extends beyond introductory theoretical exposure and contributes to the development of practical competencies among pre-service teachers. The design of dedicated courses or applied workshops grounded in authentic classroom scenarios may facilitate the translation of positive attitudes toward AI into effective pedagogical practices. Furthermore, emphasising the teacher's role as a learning designer and ethical steward in interactions with AI tools is essential.

Institutional and Policy Implications

Institutions responsible for teacher education are encouraged to make targeted investments in technological infrastructure and to ensure stable access to AI-based educational tools. The development of clear ethical frameworks and operational guidelines for AI use in educational contexts may help reduce professional concerns and enhance trust among future teachers. In addition, professional development programmes aimed at empowering teacher educators with pedagogically grounded AI competencies are strongly recommended.

Research Implications

Given the survey-based nature of the present study, future research should adopt qualitative and mixed-methods approaches to explore more deeply the lived experiences of both pre-service and in-service teachers in their use of AI. Moreover, intervention-based studies examining the effects of AI-supported training on instructional quality, professional self-efficacy, and student learning outcomes would contribute meaningfully to the development of context-sensitive knowledge in this area. Comparative research investigating cultural and institutional differences in AI adoption across teacher education systems internationally also represents a promising direction for future inquiry.

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