



## Exploring Preservice Science Teachers' AI-TPACK Competencies and Perceptions of Artificial Intelligence in Education\*

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Article Information	ABSTRACT
Received: 23.08.2025	<p>The primary purpose of this study is to investigate preservice science teachers' competencies related to AI-TPACK and their perceptions regarding the use of artificial intelligence in education. By examining these constructs, the study aims to provide insights into how preservice teachers integrate AI into their pedagogical and content knowledge and how their perceptions influence this process. This study adopted a quantitative survey research design. Specifically, two standardized instruments, the AI-TPACK and Perceptions of Artificial Intelligence in Education (PAI) scales, were administered simultaneously to preservice science teachers. The participants of this study consisted of 122 undergraduate students enrolled in the science education program at the faculty of education of a public university. The findings indicate that preservice science teachers' overall performance on the AI-TPACK scale reflected moderate competency in integrating AI into pedagogical practices. The highest mean scores highlighted willingness to integrate AI technologies into self directed learning, self-efficacy in enhancing conceptual understanding, and competence in using AI-based simulations. The findings revealed that preservice science teachers' overall results on the PAI indicated generally positive perceptions toward AI integration in education. Preservice science teachers particularly valued AI's contribution to efficiency, rapid assessment, and ease of access to information while noting potential drawbacks such as reduced student engagement and dependency. The analysis revealed a statistically significant positive correlation between preservice teachers' AI-TPACK competencies and their perceptions of AI. Results also indicated that male preservice teachers scored significantly higher in several AI-TPACK subscales. At the same time, prior AI training enhanced technological knowledge but did not necessarily improve pedagogical or content-related competencies. Overall, the findings highlight the need for targeted training opportunities emphasizing hands-on, pedagogically integrated use of AI to foster more comprehensive AI-TPACK competencies.</p> <p><b>Keywords:</b> Preservice Science Teachers, Artificial Intelligence in Education, AI-TPACK, Perceptions of AI.</p>
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### 1. INTRODUCTION

The rapid integration of artificial intelligence (AI) technologies into educational settings today necessitates that teachers and pre-service teachers become familiar with these technologies and integrate them effectively with pedagogical and content knowledge. Two key concepts have emerged in this context: Perceptions of Artificial Intelligence in Education (PAI) and AI-Technological Pedagogical Content Knowledge (AI-TPACK) competencies. Studies examining teachers' perceptions of AI highlight the dimensions of attitude and acceptance (Alejandro et al. 2024; Liu et al. 2024). Perceived usefulness, ease of use, and pedagogical beliefs are critical factors influencing teachers' intentions to adopt AI tools (Velli et al. 2024). Moreover, in line with technology acceptance models, the dimensions of perceived usefulness, ease of use, and behavioral intention can also be considered as relevant constructs in understanding teachers' perceptions and intentions toward AI integration in education. Teachers' perception of the meaningfulness of technology within educational contexts is regarded as a key element in increasing their acceptance levels (Choi et al., 2023; Zhang et al., 2023). Furthermore, teachers note AI's significant opportunities in areas

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such as lesson planning, personalized instruction, and real time student feedback. However, risks related to privacy, transparency, bias, and academic integrity are also strongly present in teachers' perceptions; in particular, the element of trust emerges as a crucial variable that reinforces intentions to use AI (Nazaretsky et al., 2025; Viberg et al., 2025). International policy documents similarly underscore the importance of equipping teachers not only from a technical standpoint but also with an ethical perspective (EU Commission, 2022; Holmes & Miao, 2023). The pedagogical uses of AI vary across disciplines. While teachers generally hold positive views about the role of AI in supporting instructional processes and material development, they express concerns regarding errors and ethical issues in assessment and evaluation processes (Alm & Ohashi, 2024). This reflects the contextual nature of how AI's role in education is perceived.

These discussions point to the need for a holistic consideration of teacher competencies. The Technological Pedagogical Content Knowledge (TPACK) theoretical framework (Mishra & Koehler, 2006) has long been employed to explain technology integration with pedagogical and content knowledge. However, recent literature emphasizes the necessity of incorporating AI specific dimensions into this model. The expanded model, referred to as AI-TPACK, defines the unique competencies required for integrating AI into educational settings.

AI-TPACK maintains the core components of the original TPACK framework, while also encompassing sub-dimensions such as AI Technological Knowledge (AI-TK), AI Pedagogical Knowledge (AI-TPK), and AI Content-Technological Knowledge (AI-TCK) (Ning et al., 2024). Some studies have additionally incorporated ethical considerations into this model. For instance, in science education, a teacher may understand machine learning based data analysis tools within the AI-TK dimension, provide individualized feedback using ChatGPT within the AI-TPK dimension, and concretize abstract chemistry concepts using molecular simulations within the AI-TCK dimension. These components collectively represent the AI-TPACK framework, which simultaneously integrates pedagogical strategies, subject matter knowledge, and technology. This framework provides a critical roadmap for teachers' effective and ethical use of AI in educational environments (Celik, 2023).

The literature highlights the transformative potential of AI-TPACK in instructional practices (Bautista et al., 2024; Choudhury et al., 2024; Karataş & Ataç, 2024; Dogan et al., 2025; Lan et al., 2025; Oved & Alt, 2025; Runge, Hebibi & Lazarides, 2025). Findings indicate that teachers are more confident in integrating AI tools into lesson design when they balance technological, pedagogical, and content knowledge (Hava & Babayiğit, 2025). However, research using assessment instruments shows that while teachers tend to be stronger in technological dimensions, they are more limited in pedagogical and ethical dimensions (Ning et al., 2024; Celik, 2023; Chiu et al., 2025).

Moreover, studies demonstrate that teachers' AI competencies are not only associated with technical knowledge but also closely related to factors such as self-efficacy, experience, institutional support, and infrastructural resources (Cabero-Almenara et al., 2024). While the influence of demographic variables is relatively limited, institutional culture and support from professional communities play a facilitating role in adopting AI. Finally, interdisciplinary and cultural differences significantly influence teachers' perceptions of AI. Teachers in STEM tend to adopt technologies more quickly, whereas ethical concerns are more prominent among language and social sciences teachers. Additionally, cultural context strongly impacts trust, risk perception, and intention to adopt (Viberg et al., 2025; Alm & Ohashi, 2024).

### **1.1. Statement of the Problem**

Despite the growing recognition of AI's role in transforming education, limited attention has been given to how preservice teachers' competencies and perceptions influence their readiness for AI integrated pedagogy. A significant limitation in the existing literature is the relative neglect of studies that examine AI-TPACK competencies and perceptions of AI together, particularly in the context of preservice science teachers. Most studies address teachers' technical competencies or perceptions separately, without focusing on the interaction between these two dimensions. However, both the AI-TPACK levels and AI-related perceptions of preservice teachers can potentially shape future classroom practices directly. Therefore, this study aims to comprehensively examine preservice science teachers' AI-TPACK competencies and perceptions of AI.

### **1.2. Purpose of the Study**

The primary purpose of this study is to investigate preservice science teachers' competencies related to AI-TPACK and their perceptions regarding the use of artificial intelligence in education. By examining these constructs, the study aims to provide insights into how preservice teachers integrate AI into their pedagogical and content knowledge and how their perceptions influence this process. The results are expected to contribute to the literature on teacher education by identifying the factors that affect the development of AI-related competencies.

### **1.3. Problem of the Study**

The increasing integration of AI in education requires teachers to develop not only technological skills but also the pedagogical capacity to incorporate AI into their teaching practices meaningfully. However, there is limited empirical evidence on preservice teachers' AI-TPACK competencies and their perceptions of AI use in educational contexts. Understanding these dimensions is

crucial for designing effective teacher education programs that prepare future teachers for AI-supported learning environments.

### 1.3.1. Sub-problems of the study

In line with the overall purpose of the research, the study was guided by several sub-problems that aimed to explore preservice science teachers' competencies in integrating AI, their perceptions of AI use in education, and the factors influencing these constructs.

1. What are the preservice science teachers' levels of AI-TPACK competencies?
2. What are the preservice science teachers' perceptions regarding the use of AI in education?
3. Is there a significant relationship between preservice science teachers' AI-TPACK competencies and their perceptions of AI in education?
4. Do preservice science teachers' AI-TPACK competencies differ significantly according to demographic variables such as gender, class level, type of secondary school graduate, urbanicity of upbringing, daily technology use, daily internet use, and prior training/experience with AI or programming?
5. Do preservice science teachers' perceptions of AI use in education, as measured by the PAI scale, differ significantly according to demographic variables?

## 2. METHODOLOGY

This study adopted a quantitative survey research design, which is widely used in educational research to obtain standardized data that allows for statistical analysis and generalization of findings (Creswell, 2014; Cohen et al., 2002). In this approach, numerical data are collected at a single point in time through structured instruments to describe participants' attitudes, perceptions, or competencies. Specifically, two standardized instruments, the AI-TPACK scale and the PAI scale, were administered simultaneously to preservice science teachers. This enabled the collection of comprehensive data regarding both their competencies in integrating AI into pedagogical practices and their perceptions of AI in educational contexts. Furthermore, the study employed a descriptive and correlational survey design, as the aim was not only to describe the current levels of participants' competencies and perceptions but also to examine potential relationships between these constructs. Descriptive statistics were used to summarize preservice science teachers' responses, providing an overview of their AI related competencies and perceptions. Correlational analysis, on the other hand, was conducted to determine the extent to which AI-TPACK competencies were associated with perceptions of AI use in education. This design is considered particularly suitable for research seeking to identify patterns and associations without manipulating variables (Fraenkel & Wallen, 2009). In line with this methodological framework, the following section presents detailed information regarding the study participants, including their demographic characteristics and data collection tools.

### 2.1. Participants

The participants of this study consisted of 122 undergraduate students enrolled in the science education program at the faculty of education of a public university. A convenience sampling strategy was employed, involving preservice science teachers from different grade levels at a public university, who were accessible and voluntarily participated in the study. The demographic characteristics presented in Table 1 highlight the diversity of preservice science teachers in terms of gender, class level, educational background, and prior experience with technology and AI. These variables were considered important for examining potential differences in AI-TPACK competencies and perceptions of AI in education. As participants represent diverse secondary school backgrounds and varying levels of prior AI or programming training, the study aims to explore whether these background differences influence preservice teachers' overall AI-TPACK competencies and perceptions of AI in education, or whether such competencies and perceptions develop independently of prior experience.

Table 1.  
*Demographic Information of the Participants*

		Frequency (N)	Percentage (%)
<b>Gender</b>	Female	90	74
	Male	32	26
<b>Classe</b>	1	18	15
	2	41	34
	3	43	35
	4	20	16
<b>Urbanicity of Upbringing</b>	City	58	48
	District	49	40
	Village	15	12
<b>Type of Secondary School Graduated</b>	Science School	17	14
	High School		

	Anatolian High School	88	72
	Imam Hatip High School	17	14
<b>Daily Use of Technology (e.g., Computers, etc.)</b>	0-3 h	32	26
	3-5 h	55	45
	More than 5 h	35	29
<b>Daily Internet Usage (including via mobile phone)</b>	0-3 h	29	24
	3-5 h	56	46
	More than 5 h	37	30
<b>Prior Experience with Technology-Assisted Teaching</b>	Yes	52	43
	No	70	57
<b>Prior Training in Artificial Intelligence</b>	Yes	20	16
	No	102	84
<b>Prior Training in Software/Programming</b>	Yes	7	6
	No	115	94
<b>Total</b>		122	100

## 2.2. Data Collection Tools

### 2.2.1. Perception Scale Regarding Artificial Intelligence Use in Education (PAI)

The teachers' perception scale regarding artificial intelligence use in education (PAI), developed by Üzümlü et al. (2025), consists of 15 items and three sub dimensions: Teaching Perception (TP), Learning Perception (LP), and Ethical Perception (EP). In the PAI scale, participants responded using a 5-point Likert scale ranging from strongly agree (5) to strongly disagree (1). This scale enabled respondents to express the extent of their agreement with each item, thereby capturing varying levels of perception and attitude. To examine construct validity, a confirmatory factor analysis (CFA) was conducted, and the fit indices were found to be within acceptable thresholds ( $\chi^2/df < 3$ ; CFI and TLI  $> .90$ ; RMSEA  $< .08$ ). These results indicate that the theoretical model of the scale is statistically supported, and the factor structure demonstrates adequate construct validity. The reliability of the scale was assessed using Cronbach's alpha coefficients. The internal consistency for the total scale was found to be  $\alpha = .87$ . At the same time, the subdimensions ranged between .79 and .82: TP ( $\alpha = .79$ ), LP ( $\alpha = .82$ ), and EP ( $\alpha = .80$ ). These findings demonstrate that the scale has high internal consistency at both the overall and subscale levels. Furthermore, the significant item total correlations provide additional evidence that the instrument is a reliable tool for research on teachers' perceptions regarding using AI in education. Since the original version of this scale was developed in Turkish, it was used as is.

### 2.2.2. Artificial Intelligence - Technological Pedagogical Content Knowledge (AI-TPACK) Scale

The AI-TPACK scale developed by Ning et al. (2024) is structured around seven subdimensions, each reflecting a specific intersection of AI knowledge with pedagogical, technological, and content domains. These dimensions include Content Knowledge (CK;  $\alpha = .809$ ), Pedagogical Knowledge (PK;  $\alpha = .837$ ), AI Technological Knowledge (AI-TK;  $\alpha = .912$ ), Pedagogical Content Knowledge (PCK;  $\alpha = .806$ ), AI Technological Content Knowledge (AI-TCK;  $\alpha = .945$ ), AI Technological Pedagogical Knowledge (AI-TPK;  $\alpha = .942$ ), and AI Technological Pedagogical Content Knowledge (AI-TPACK;  $\alpha = .931$ ). The reliability analysis for the overall scale yielded a Cronbach's alpha coefficient of .957. This multidimensional framework comprehensively assesses teachers' competencies and perceptions regarding integrating AI into educational practice. In the AI-TPACK scale, participants responded using a 5 point Likert format ranging from strongly conformant (1) to strongly non-conformant (5). This format allowed respondents to indicate the degree of conformity of each item to their personal experiences and circumstances. The AI-TPACK scale, originally developed by Ning et al. (2024), was adapted into Turkish by Canbazoglu Bilici, Tanrisevdi, Yildiz Durak, and Çakiroglu (2024). The adaptation study was conducted on the 39 items, five point Likert-type scale, and administered to science teachers. A CFA was performed to examine the structural validity of the Turkish version, and the results confirmed that the scale preserved its original seven factors structure. The reliability analyses demonstrated that the Turkish scale has high internal consistency. The Cronbach's alpha coefficient for the total scale was reported as .980. The reliability coefficients for the sub-dimensions were as follows: CK ( $\alpha = .873$ ), PK ( $\alpha = .888$ ), AI-TK ( $\alpha = .954$ ), PCK ( $\alpha = .928$ ), AI-TCK ( $\alpha = .973$ ), AI-TPK ( $\alpha = .970$ ), and AI-TPACK ( $\alpha = .946$ ). These findings provide evidence that the Turkish version of the scale is a valid and reliable instrument for assessing teachers' technological pedagogical content knowledge in the context of artificial intelligence.

In the present study, we deliberately focused on four subdimensions of the AI-TPACK scale (AI-TK, AI-TCK, AI-TPK, and AI-TPACK), as these domains are directly related to the integration of AI into teaching and learning practices. While the original

scale encompasses seven factors, the subdimensions of CK, PK, and PCK reflect more general aspects of teachers' knowledge that are not necessarily AI specific. In contrast, the selected four factors explicitly address how preservice science teachers perceive and operationalize AI within technological, pedagogical, and content related contexts. The Cronbach's alpha coefficients for these dimensions (AI-TK, AI-TCK, AI-TPK, and AI-TPACK) demonstrated high internal consistency, confirming that the adapted instrument was psychometrically sound for this research. The details of these reliability analyses are presented in the data analysis section.

### 2.3. Data Analysis

Before conducting the primary analyses, the distribution characteristics of the data obtained from the PAI scale and the AI-TPACK scale were examined to determine whether they met the assumptions of normality. The results of the normality tests are presented in Table 2, which indicates that the distributions of both scales were within acceptable thresholds for normality. Furthermore, the visual inspection of the Normal Q-Q Plots (Figure 1) confirmed that the data points closely followed the expected diagonal line. Based on these findings, it was concluded that the scale scores exhibited a normal distribution. Therefore, subsequent statistical analyses were conducted using parametric tests.

Table 2. *Normality Test Results for PAI and AI-TPACK Scale*

Scale	Skewness	Skewness Std. Error	Kurtosis	Kurtosis Std. Error	Shapiro-Wilk (p)	Normality
PAI	0.220	0,219	0.171	0,435	0.979 (p = .055)	Normal
AI-TPACK	-0.136	0,219	-0.163	0,435	0.987 (p = .296)	Normal

The normality of the data was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Results indicated that both the PAI and AI-TPACK scales followed a normal distribution, as the test statistics were non-significant ( $p > .05$ ). In addition, skewness and kurtosis values fell within the acceptable range of -1 to +1 (Tabachnick & Fidell, 2013). Therefore, parametric statistical tests were employed in subsequent analyses.

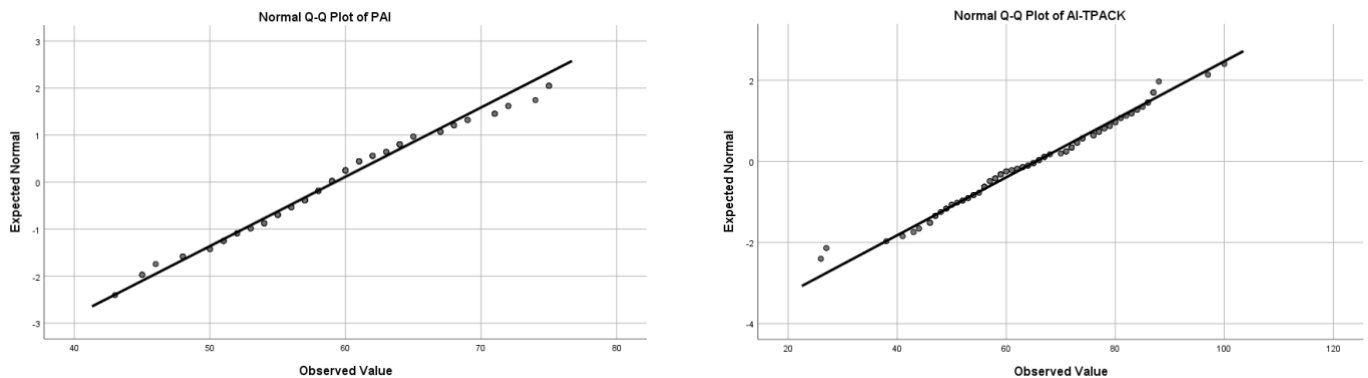


Figure 1. Normal Q-Q plots of PAI and AI-TPACK scale scores

A series of statistical analyses was conducted to examine the relationships between the demographic variables and the main study scales (PAI and AI-TPACK). Independent samples t-tests were employed for binary demographic variables such as gender, prior experience with technology assisted teaching, and prior training in AI. Since the sample sizes across groups were highly unequal for prior training in software/programming, and normality assumptions could not be ensured for the smaller group, a non-parametric Mann Whitney U test was conducted to provide a more robust comparison. For demographic variables with more than two categories, including class level, urbanicity of upbringing, type of secondary school graduated from, daily use of technology, and daily internet usage, one-way ANOVA tests were performed to compare group means. All analyses were conducted using a significance level of  $\alpha = .05$ . Along with p values, we reported effect size for each independent-samples t test using Cohen's d based on the pooled standard deviation. In accordance with the general guidelines for sample adequacy in factor analysis, a minimum participant to item ratio of 5:1 is considered the lower acceptable limit (Gorsuch, 1983; Kline, 2016). Moreover, a total sample size between 100 and 200 participants is regarded as acceptable for confirmatory factor analysis when the model structure is relatively simple and factor loadings are strong (Kline, 2016).

Table 3. *Reliability and Descriptive Statistics of Scales*

Scales and Subscales	N	Number of items	Cronbach's Alpha
<b>PAI Scale</b>	122	15	.804
Teaching perception	122	7	.839
Learning perception	122	4	.806

Ethical perception	122	4	.710
<b>AI-TPACK Scale</b>	122	22	.952
AI-TPACK-TK	122	5	.839
AI-TPACK-TCK	122	6	.873
AI-TPACK-TPK	122	6	.889
AI-TPACK-TPACK	122	5	.843

Cronbach's alpha analyses were conducted for both the PAI and AI-TPACK scales to examine the reliability of the instruments (Table 3). The overall reliability coefficient of the PAI scale was found to be .804. In addition, the reliability coefficients of its three subfactors, TP, LP, and EP, were .839, .806, and .710, respectively. These results indicate that the PAI scale, including its subdimensions, can be considered a reliable measurement instrument, since Cronbach's alpha values above .70 are generally accepted as evidence of sufficient reliability for psychometric tools. Similarly, the overall reliability of the AI-TPACK scale was calculated as .952. The reliability coefficients of its four subfactors, AI-TPACK-TK, AI-TPACK-CK, AI-TPACK-PK, and AI-TPACK-TPCK, were .839, .873, .889, and .843, respectively. Based on these results, the AI-TPACK scale and its subdimensions also demonstrate high internal consistency, further confirming the reliability of this instrument.

### 3. FINDINGS

The findings are structured according to the study's five subproblems, addressing AI-TPACK competency levels, perceptions of AI in education, the correlation between the two scales, and differences across demographic variables.

#### 3.1. Preservice Science Teachers' AI-TPACK Competency Levels

The findings indicate that preservice science teachers' overall mean score on the AI-TPACK scale was 2.96 (SD = 0.90), which suggests a moderate level of competency in integrating AI into pedagogical practices (Table 4). This finding implies that while preservice science teachers display a certain level of confidence in utilizing AI technologies for educational purposes, their competencies remain developing rather than advanced. Among the items, the highest mean scores were observed in item 22 (M = 3.43, SD = 0.96), item 11 (M = 3.36, SD = 0.94), and item 20 (M = 3.25, SD = 0.94). The high score for item 22 indicates that preservice science teachers show a strong willingness to integrate AI technologies into their own learning processes, emphasizing its role in self directed learning and professional growth. The second highest score, item 11, highlights their strong sense of self efficacy in employing AI to enhance students' conceptual understanding, which is a critical component of effective science instruction. Furthermore, the relatively high mean score of item 20 reveals that preservice teachers perceive themselves as competent in using AI based simulations to support teaching practices, reflecting their recognition of AI's potential to enrich the instructional process in science education.

Table 4.

*Descriptive Statistics of Preservice Science Teachers' AI-TPACK Competency Items*

No	Items	Mean	sd
1	I am familiar with commonly encountered AI technologies in the educational environment.	2,84	,79
2	I possess the capability to easily acquire AI technologies necessary for teaching.	3,02	,90
3	I frequently incorporate AI technologies in the pedagogical context.	2,53	,88
4	I am proficient in using AI technologies to enhance the instructional process.	2,72	,87
5	I am knowledgeable about using AI technologies for interactive teaching purposes.	2,70	,89
6	I am familiar with AI in specific academic domains, such as mathematical intelligent tutoring systems.	2,92	,84
7	I am capable of effortlessly using AI in specific academic domains.	2,74	,88
8	I am proficient in using AI to update my knowledge base within the academic discipline.	2,71	,88
9	I can select appropriate AI tools based on the subject matter I am teaching.	3,23	,98
10	I am adept at using AI to effectively enhance students' comprehension of the material.	2,92	,88
11	I can use AI to broaden the knowledge horizons of students.	3,36	,95
12	I am capable of using AI to enhance my pedagogical perspectives.	2,84	,83
13	I am able to apply appropriate AI in various teaching activities.	3,16	,82
14	I have the capacity to select AI to sustain students' motivation and interest.	3,06	,90
15	I can apply AI to assess the learning outcomes of students.	3,27	,89

16	I am proficient in using AI to optimize classroom instructional management.	2,93	,98
17	I possess the ability to explain information derived from AI to provide real-time feedback.	2,85	,96
18	I am knowledgeable in integrating AI with educational content and teaching methods to improve classroom teaching efficiency and effectiveness.	2,85	,84
19	I am capable of selecting appropriate teaching methods and AI based on the educational content for instruction.	3,11	,98
20	I can use AI to create, simulate, and adapt scenarios that are in line with the educational content.	3,25	,94
21	I can use personalized AI to select suitable teaching methods as well as guide students in practical learning.	3,03	,94
22	I will use AI for self-directed learning, further deepening my subject knowledge and understanding of educational pedagogical theories.	3,43	,96
Total		2,96	0,90

### 3.2. Preservice Science Teachers' Perceptions Regarding the Use of Artificial Intelligence in Education

The findings revealed that preservice science teachers' overall mean score on the PAI was 3.95 (SD = 0.86), indicating generally positive perceptions toward AI integration in education (Table 5). The highest rated items (12, 7, 14) were "It gets people used to effortless" (M = 4.34, SD = 0.76), "It provides rapid evaluation" (M = 4.34, SD = 0.75), and "It gets people used to ready-made information" (M = 4.31, SD = 0.75). These results suggest that teacher candidates particularly value AI's contribution to efficiency, rapid assessment, and ease of access to information.

Table 5.  
*Descriptive Statistics of Preservice Science Teachers' PAI Items*

No	Items	Mean	sd
1	Artificial intelligence makes planning easier in teaching.	4,07	,72
2	It supports the monitoring of the teaching process.	3,98	,77
3	It offers contextual richness.	4,28	,73
4	It supports individualized instruction.	3,85	,90
5	It facilitates teaching difficult and complex subjects.	3,97	,83
6	It provides continuity in feedback.	3,70	,93
7	It provides rapid evaluation.	4,34	,75
8	It brings in reasoning ability.	3,43	,99
9	It increases motivation.	3,68	1,00
10	It encourages self-learning.	3,58	1,14
11	It increases curiosity in learning.	3,60	1,14
12	It gets people used to effortless.	4,34	,76
13	It bears ethical threats.	3,93	,74
14	It gets people used to ready-made information.	4,31	,75
15	It trivializes information.	4,17	,74
Total		3,95	,86

### 3.3. Correlation Between AI-TPACK and PAI Scores

The relationship between preservice science teachers' AI-TPACK competencies and their perceptions of AI in education was examined to determine the degree of association between these two constructs (Table 6). Analyzing this correlation is important for understanding how preservice science teachers' competencies in integrating AI into pedagogical practices align with their overall perceptions of AI use in education. The analysis revealed a statistically significant positive correlation between preservice science teachers' AI-TPACK competencies and their perceptions of AI ( $r=.194$ ,  $p<.05$ ). Although the correlation coefficient indicates a low level of association, the findings suggest that higher levels of AI-TPACK competencies are modestly related to more positive perceptions of AI in education.

Table 6.  
*Correlation Analysis of AI-TPACK and PAI Scales*

		PAI
AI-TPACK	Pearson r	.194*
	p	.032
	n	122

\* Correlation is significant at 0.05.

### 3.4. Differences in AI-TPACK Scores Across Demographic Variables

The results of the study are presented according to preservice science teachers' AI-TPACK competencies across various demographic variables. Investigating demographic differences in AI-TPACK competencies is essential, as prior research indicates that variables such as gender, experience, and educational background may influence teachers' technology related self-efficacy and integration practices (Cabero-Almenara et al., 2024; Hava & Babayiğit, 2025). Each subsection reports the statistical outcomes for the related variable along with brief interpretations.

Table 7.  
*t-Test Results of Preservice Science Teachers' AI-TPACK Scale Scores by Gender*

PAI Scale	Gender	N	$\bar{X}$	sd	t	p	Cohen's d
AITPACK-TK	Female	90	13,59	3,12	-1.313	.192	0.27
	Male	32	14,50	4,01			
AITPACK-TCK	Female	90	17,37	3,89	-2.278	.025	0.47
	Male	32	19,31	4,82			
AITPACK-TPK	Female	90	17,58	4,08	-2.301	.023	0.47
	Male	32	19,59	4,72			
AITPACK-TPACK	Female	90	15,23	3,42	-2.305	.023	0.47
	Male	32	16,94	4,06			
Total Scale (AI-TPACK)	Female	90	63,77	13,12	-2.326	.022	0.48
	Male	32	70,34	15,37			

Statistical significance  $\alpha = .05$  level.

Table 7 presents the results of an independent samples t-test conducted to examine whether preservice science teachers' AI-TPACK scale scores differed significantly by gender. The findings reveal that while there was no statistically significant difference between female ( $M = 13.59$ ,  $SD = 3.12$ ) and male ( $M = 14.50$ ,  $SD = 4.01$ ) preservice teachers on the AI-TPACK-TK subscale ( $t = -1.313$ ,  $p = .192$ ), significant gender differences emerged in several other subscales. Specifically, male preservice science teachers scored significantly higher than females in AI-TPACK-TCK ( $t = -2.278$ ,  $p = .025$ ), AI-TPACK-TPK ( $t = -2.301$ ,  $p = .023$ ), and AI-TPACK-TPACK ( $t = -2.305$ ,  $p = .023$ ). Furthermore, when considering the total AI-TPACK scale score, male preservice teachers ( $M = 70.34$ ,  $SD = 15.374$ ) demonstrated significantly higher levels compared to their female counterparts ( $M = 63.77$ ,  $SD = 13.12$ ), ( $t = -2.326$ ,  $p = .022$ ). Effect size values were calculated using Cohen's d, which indicated small to moderate effects across the subscales (ranging from  $d = 0.27$  to  $d = 0.48$ ).

Table 8.  
*t-Test Results of Preservice Science Teachers' AI-TPACK Scale Scores by Prior Experience with Technology Assisted Teaching*

Scale Factor	Prior Experience with Technology Assisted Teaching	N	$\bar{X}$	sd	t	p	Cohen's d
AITPACK-TK	Yes	52	14,12	3,14	.808	.420	0.15
	No	70	13,61	3,56			
AITPACK-TCK	Yes	52	17,92	3,98	.103	.918	0.02
	No	70	17,84	4,43			
AITPACK-TPK	Yes	52	18,21	4,22	.230	.819	0.04
	No	70	18,03	4,44			
AITPACK-TPACK	Yes	52	15,75	3,58	.181	.857	0.03
	No	70	15,63	3,74			
Total Scale (AI-TPACK)	Yes	52	66,00	13,29	.345	.731	0.06
	No	70	65,11	14,57			

Table 8 presents the independent samples t-test results examining whether preservice teachers' AI-TPACK scores differ according to their prior experience with technology-assisted teaching. The findings indicate that there were no statistically significant differences across any of the AI-TPACK subscales or the total scale. For the AI-TPACK-TK subscale, preservice teachers with prior experience ( $M = 14.12$ ,  $SD = 3.14$ ) and those without experience ( $M = 13.61$ ,  $SD = 3.56$ ) did not differ significantly ( $t = .808$ ,  $p = .420$ ). Similarly, no meaningful differences were found in AI-TPACK-TCK ( $t = .103$ ,  $p = .918$ ), AI-TPACK-TPK ( $t = .230$ ,  $p = .819$ ), or AI-TPACK-TPACK ( $t = .181$ ,  $p = .857$ ). When considering the overall AI-TPACK scale, preservice teachers with prior experience in technology-assisted teaching ( $M = 66.00$ ,  $SD = 13.29$ ) scored slightly higher than those without

such experience ( $M = 65.11$ ,  $SD = 14.57$ ), yet this difference was not statistically significant ( $t = .345$ ,  $p = .731$ ). Across all comparisons, effect sizes were trivial to small ( $d = .02-.15$ ), indicating negligible practical differences between groups with and without prior technology-assisted teaching experience.

Table 9.

*t-Test Results of Preservice Science Teachers' AI-TPACK Scale Scores by Prior Training in AI*

Scale Factor	Prior Training in Artificial Intelligence	N	$\bar{X}$	sd	t	p	Cohen's d
AITPACK-TK	Yes	20	15,90	2,65	3.102	.002	0.76
	No	102	13,42	3,37			
AITPACK-CK	Yes	20	18,80	3,11	1.070	.287	0.26
	No	102	17,70	4,40			
AITPACK-PK	Yes	20	18,50	3,86	.443	.659	0.11
	No	102	18,03	4,43			
AITPACK-TPCK	Yes	20	15,55	3,20	-.174	.862	0.04
	No	102	15,71	3,75			
Total Scale (AI-TPACK)	Yes	20	68,75	11,00	1.141	.256	0.28
	No	102	64,85	14,46			

The independent samples t-test results presented in the table 9 examine whether preservice teachers' AI-TPACK scores differ significantly based on their prior training in AI. The findings reveal that a statistically significant difference emerged only in the AI-TPACK Technological Knowledge (AITPACK-TK) subscale ( $t = 3.102$ ,  $p = .002$ ). Specifically, preservice teachers who had received prior AI training ( $M = 15.90$ ,  $SD = 2.65$ ) scored significantly higher than those without such training ( $M = 13.42$ ,  $SD = 3.37$ ). For the other subscales AITPACK-TCK, AITPACK-TPK, and AITPACK-TPACK as well as the overall AI-TPACK scale, no statistically significant differences were observed ( $p > .05$ ), although participants with AI training consistently showed slightly higher mean scores than their counterparts. Effect size values indicated that the difference in AI-TPACK-TK was large ( $d = 0.76$ ), whereas other subscales and the total score showed small or negligible effects (ranging from  $d = 0.04$  to  $d = 0.28$ ).

Table 10.

*Mann-Whitney U Test Results of Preservice Teachers' AI-TPACK Scale Scores by Prior Training in Software/Programming*

Scale Factor	Prior Training in Software/Programming	N	Mean Rank	U	z	p
AITPACK-TK	Yes	7	79,43	277	-	1.389
	No	115	60,43			
AITPACK-TCK	Yes	7	81,86	260	-	1.574
	No	115	60,26			
AITPACK-TPK	Yes	7	70,71	338	-	.712
	No	115	60,94			
AITPACK-TPACK	Yes	7	65,07	377,5	-	.277
	No	115	61,28			
Total Scale (AI-TPACK)	Yes	7	77,07	293,5	-	1.201
	No	115	60,65			

Table 10 presents the results of the Mann Whitney U test conducted to examine whether preservice teachers' AI-TPACK scale scores differed significantly according to their prior training in software or programming. The table includes the mean ranks, U values, and corresponding p values for each AI-TPACK subscale (AI-TPACK-TK, AI-TPACK-TCK, AI-TPACK-TPK, AI-TPACK-TPACK) as well as the total AI-TPACK score. The mean ranks indicate that preservice teachers with prior training in software or programming ( $n=7$ ) consistently achieved higher average ranks than those without such training ( $n=115$ ) across all subscales. Across all dimensions of the AI-TPACK scale, AITPACK-TK, AITPACK-CK, AITPACK-PK, and AITPACK-TPCK no statistically significant differences were found between participants with prior training and those without ( $p > .05$  for all comparisons).

Table 11.

*ANOVA Results of Preservice Science Teachers' AI-TPACK Scale Scores by Class Level*

Class	N	$\bar{X}$	sd	F	p
1 <sup>st</sup>	18	70,11	12,461	1,831	.145
2 <sup>nd</sup>	41	64,73	13,274		
3 <sup>rd</sup>	43	62,56	14,290		
4 <sup>th</sup>	20	69,20	15,137		
Total	122	65,49	13,987		

The ANOVA results presented in Table 11 examine the differences in preservice teachers' AI-TPACK scale scores across class levels. The mean scores range from 62.56 (3rd year) to 70.11 (1st year), with standard deviations varying between 12.461 and 15.137. Despite these variations in average scores, the ANOVA test revealed no statistically significant differences across the four class levels ( $F = 1.831$ ,  $p = .145$ ).

Table 12.

*ANOVA Results of Preservice Science Teachers' AI-TPACK Scale Scores by Urbanicity of Upbringing*

Urbanicity of Upbringing	N	$\bar{X}$	sd	F	p
City	58	67,05	12,348	.822	.442
District	49	63,57	15,193		
Village	15	65,73	15,984		
Total	122	65,49	13,987		

Table 12 presents the ANOVA results of preservice teachers' AI-TPACK scale scores by urbanicity of upbringing. The mean scores were 67.05 for participants raised in cities, 63.57 for those from districts, and 65.73 for those from villages. Although minor variations are observed across the groups, the ANOVA test indicated no statistically significant differences among them ( $F = 0.822$ ,  $p = .442$ ).

Table 13.

*Descriptive Statistics of Preservice Science Teachers' AI-TPACK Scores by Type of Secondary School Graduated*

Type of Secondary School Graduated	N	$\bar{X}$	sd	F	p
Science High School	17	61,59	13,067	1.074	.345
Anatolian High School	88	66,59	13,838		
İmam Hatip High School	17	63,71	15,531		
Total	122	65,49	13,987		

The table 13 the descriptive statistics of preservice teachers' AI-TPACK scores based on the type of secondary school they graduated from (Science High School, Anatolian High School, and Imam Hatip High School). The results show that preservice teachers from Anatolian High Schools obtained the highest mean score ( $M = 66.59$ ,  $SD = 13.838$ ), followed by those from Imam Hatip High Schools ( $M = 63.71$ ,  $SD = 15.531$ ), and Science High Schools ( $M = 61.59$ ,  $SD = 13.067$ ). Despite these variations in mean scores, the ANOVA results ( $F = 1.074$ ,  $p = .345$ ) indicate that the differences across groups are not statistically significant. This suggests that the type of secondary school graduated does not exert a meaningful effect on preservice teachers' AI-TPACK competencies.

Table 14.

*Descriptive Statistics of Preservice Teachers' AI-TPACK Scale Scores by Daily Use of Technology*

Daily Use of Technology (e.g., Computers, etc.)	N	$\bar{X}$	sd	F	p
0-3 h	32	66,28	11,846	1.539	.219
3-5 h	55	67,22	15,369		
More than 5 h	35	62,06	13,249		
Total	122	65,49	13,987		

Table 14 presents the descriptive statistics and ANOVA results of preservice teachers' AI-TPACK scores according to their daily use of technology (e.g., computers). The mean scores indicate that preservice science teachers who reported using technology for 3–5 hours per day ( $M = 67.22$ ) demonstrated slightly higher AI-TPACK competencies compared to those who used it for 0–

3 hours ( $M = 66.28$ ) and those who used it for more than 5 hours daily ( $M = 62.06$ ). Despite these numerical differences, the ANOVA results ( $F = 1.539$ ,  $p = .219$ ) show that the differences were not statistically significant.

Table 15.

*Descriptive Statistics of Preservice Science Teachers' AI-TPACK Scale Scores by Daily Internet Usage*

Daily Internet Usage (including via mobile phone)	N	$\bar{X}$	sd	F	p
0-3 h	29	64,83	12,151	1.011	.367
3-5 h	56	67,34	14,529		
More than 5 h	37	63,22	14,463		
Total	122	65,49	13,987		

The results in Table 15 present the ANOVA findings regarding preservice teachers' AI-TPACK scores based on their daily internet usage (including via mobile phones). The mean scores show slight variations among the groups: preservice teachers using the internet for 3-5 hours daily reported the highest mean score ( $M = 67.34$ ), compared to those with 0-3 hours ( $M = 64.83$ ) and those with more than 5 hours ( $M = 63.22$ ). Despite these differences, the ANOVA test indicated that the differences were not statistically significant ( $F = 1.011$ ,  $p = .367$ ).

### 3.5. Differences in PAI Scores Across Demographic Variables

The analysis of preservice science teachers' PAI scores was conducted with respect to various demographic characteristics. The results for each variable are presented separately, accompanied by interpretations highlighting potential differences or similarities.

Table 16.

*t-Test Results of Preservice Science Teachers' PAI Scale Scores by Gender*

PAI Scale	Gender	N	$\bar{X}$	sd	t	p	Cohen's d
Teaching perception	Female	90	28,19	3,94	-.036	.972	0.01
	Male	32	28,22	4,38			
Learning perception	Female	90	14,42	3,26	-.734	.464	0.15
	Male	32	13,91	3,83			
Ethical perception	Female	90	16,51	2,24	-1.981	.050	0.41
	Male	32	17,41	2,06			
Total Scale	Female	90	59,12	6,70	-.292	.771	0.06
	Male	32	59,53	7,12			

The results of the independent samples t-test revealed that preservice science teachers' scores on the PAI scale did not significantly differ by gender (Table 16). For the TP subscale, the mean scores of females ( $M = 28.19$ ,  $SD = 3.94$ ) and male participants ( $M = 28.22$ ,  $SD = 4.38$ ) were nearly identical, with no significant difference ( $t = -0.036$ ,  $p = .972$ ). Similarly, for the LP subscale, although female participants ( $M = 14.42$ ,  $SD = 3.26$ ) scored slightly higher than their male counterparts ( $M = 13.91$ ,  $SD = 3.83$ ), this difference was not statistically significant ( $t = -0.734$ ,  $p = .464$ ). On the EP subscale, female participants ( $M = 16.51$ ,  $SD = 2.24$ ) scored marginally lower than male participants ( $M = 17.41$ ,  $SD = 2.06$ ). This difference approached the threshold of statistical significance ( $t = -1.981$ ,  $p = .050$ ), suggesting a potential tendency for male participants to report higher ethical perceptions regarding AI use. However, it still falls at the borderline of conventional significance levels. Finally, for the Total Scale, no significant gender difference was found (female:  $M = 59.12$ ,  $SD = 6.70$ ; male:  $M = 59.53$ ,  $SD = 7.12$ ;  $t = -0.292$ ,  $p = .771$ ). The effect size analysis (Cohen's d) indicated negligible to small differences across all subscales, except for the ethical perception dimension ( $d = 0.41$ ), which demonstrated a small-to-moderate effect favoring male participants. Overall, these findings indicate that gender does not play a significant role in preservice teachers' perceptions of AI in education as measured by the PAI scale, though a near-significant trend was observed in the EP dimension.

Table 17.

*t-Test Results of Preservice Science Teachers' PAI Scale Scores by Prior Experience with Technology Assisted Teaching*

PAI Scale	Prior Experience with Technology Assisted Teaching	N	$\bar{X}$	sd	t	p	Cohen's d
Teaching perception	Yes	52	28,46	4,50	.623	.534	0.11

Learning perception	No	70	28,00	3,68			
	Yes	52	14,79	3,10	1.407	.162	0.26
Ethical perception	No	70	13,91	3,59			
	Yes	52	16,54	2,49	-.888	.376	-0.16
Total Scale	No	70	16,90	2,00			
	Yes	52	59,79	7,28	.783	.435	0.14
	No	70	58,81	6,41			

The independent samples t-test results demonstrated that preservice science teachers' prior experience with technology-assisted teaching did not significantly influence their scores on the PAI scale or its subdimensions (Table 17). For the TP subscale, participants with prior experience ( $M = 28.46$ ,  $SD = 4.50$ ) and those without experience ( $M = 28.00$ ,  $SD = 3.68$ ) did not differ significantly ( $t = 0.623$ ,  $p = .534$ ). Similarly, in the LP subscale, preservice teachers with prior experience ( $M = 14.79$ ,  $SD = 3.10$ ) reported slightly higher scores compared to those without such experience ( $M = 13.91$ ,  $SD = 3.59$ ), yet this difference was not statistically significant ( $t = 1.407$ ,  $p = .162$ ). In terms of EP, participants with prior experience ( $M = 16.54$ ,  $SD = 2.49$ ) and those without ( $M = 16.90$ ,  $SD = 2.00$ ) also showed no significant difference ( $t = -0.888$ ,  $p = .376$ ). Finally, for the total scale scores, preservice teachers with prior experience ( $M = 59.79$ ,  $SD = 7.28$ ) did not significantly differ from their counterparts without experience ( $M = 58.81$ ,  $SD = 6.41$ ;  $t = 0.783$ ,  $p = .435$ ). Effect sizes indicated small differences across dimensions (TP  $d = 0.11$ ; LP  $d = 0.26$ ; EP  $d = -0.16$ ; Total  $d = 0.14$ ), suggesting that prior experience with technology-assisted teaching had only a limited practical impact on PAI scores. Overall, these findings suggest that having prior experience with technology-assisted teaching does not exert a statistically significant impact on preservice teachers' perceptions of AI in education across the teaching, learning, and ethical dimensions of the PAI scale.

Table 18.

*t-Test Results of Preservice Science Teachers' PAI Scale Scores by Prior Training in AI*

PAI Scale	Prior Training in Artificial Intelligence	N	$\bar{X}$	sd	t	p	Cohen's d
Teaching perception	Yes	20	29,00	4,89	.973	.332	0.24
	No	102	28,04	3,86			
Learning perception	Yes	20	15,55	3,28	1.831	.070	0.45
	No	102	14,04	3,39			
Ethical perception	Yes	20	16,40	2,60	-.760	.449	0.18
	No	102	16,81	2,15			
Total Scale	Yes	20	60,95	8,67	1.243	.216	0.31
	No	102	58,89	6,35			

The independent samples t-test was conducted to examine whether preservice teachers' scores on the PAI scale differed significantly according to their prior training in AI. As shown in the table 18, participants with prior AI training ( $n=20$ ) had slightly higher mean scores across the TP ( $M = 29.00$ ,  $SD = 4.89$ ) and LP ( $M = 15.55$ ,  $SD = 3.28$ ) subscales compared to those without such training ( $M = 28.04$ ,  $SD = 3.856$ ;  $M = 14.04$ ,  $SD = 3.39$ , respectively). However, these differences were not statistically significant ( $p > .05$ ). Similarly, in the EP subscale, the mean score of participants without AI training ( $M = 16.81$ ,  $SD = 2.15$ ) was slightly higher than that of those with AI training ( $M = 16.40$ ,  $SD = 2.604$ ), but the difference again was not significant ( $t = -0.760$ ,  $p = .449$ ). Finally, the analysis of the total scale scores revealed that participants with AI training ( $M = 60.95$ ,  $SD = 8.672$ ) scored marginally higher than those without training ( $M = 58.89$ ,  $SD = 6.35$ ). Nonetheless, this difference was also not statistically significant ( $t = 1.243$ ,  $p = .216$ ). The effect size analysis revealed small to moderate effects across the subscales (range = 0.18–0.45), suggesting that while prior AI training did not lead to statistically significant differences, it was associated with slightly higher perceptions of AI use among preservice teachers. In sum, while preservice teachers with prior AI training tended to score slightly higher on certain dimensions of the PAI scale, the differences were not statistically significant, indicating that prior AI training did not exert a measurable effect on participants' overall perceptions captured by the scale.

Table 19.

*Mann-Whitney U Test Results of Preservice Science Teachers' PAI Scale Scores by Prior Training in Software/Programming*

Scale Factor	Prior Training in Software/Programming	N	Mean Rank	U	z	p
Teaching perception	Yes	7	56,14	365	-415	.678
	No	115	61,83			
Learning perception	Yes	7	70,50	339,5	-697	.486
	No	115	60,95			
Ethical perception	Yes	7	76,07	300,5	1.136	.256
	No	115	60,61			
Total Scale	Yes	7	63,14	391	-.127	.899
	No	115	61,40			

Table 19 presents the results of the Mann Whitney U test conducted to determine whether preservice science teachers' PAI scale scores differed significantly based on their prior training in software or programming. As shown in the table, participants with prior software/programming training and those without such training did not exhibit statistically significant differences across any of the PAI subscales or the total scale ( $p > .05$  for all comparisons). The mean ranks for participants with prior training were 56.14 for TP, 70.50 for LP, 76.07 for EP, and 63.14 for the total scale, indicating a tendency toward slightly higher perceptions among those with training; however, these differences were not statistically significant.

Table 20.

*ANOVA Results of Preservice Teachers' PAI Scale Scores by Class Level*

Class	N	$\bar{X}$	Standard Deviation	F	p
1.	18	58,33	5,380	.383	.766
2.	41	60,10	5,924		
3.	43	58,79	7,812		
4.	20	59,20	7,452		
Total	122	59,23	6,783		

The one-way ANOVA results presented in Table 20 indicate that preservice science teachers' PAI scale scores did not differ significantly across class levels. The mean scores were 58.33 (SD = 5.380) for first year students, 60.10 (SD = 5.924) for second year students, 58.79 (SD = 7.812) for third year students, and 59.20 (SD = 7.452) for fourth year students. The overall mean score was 59.23 (SD = 6.783). The ANOVA test yielded an F value of 0.383 with a significance level of  $p = .766$ , which is greater than the threshold of .05. This result demonstrates that there were no statistically significant differences in PAI scale scores among preservice science teachers based on their class level.

Table 21.

*ANOVA Results of Preservice Science Teachers' PAI Scale Scores by Urbanicity of Upbringing*

Urbanicity of Upbringing	N	$\bar{X}$	Standard Deviation	F	p
City	58	59,45	7,64	.014	.869
District	49	59,22	5,92		
Village	15	58,40	6,24		
Total	122	59,23	6,78		

Table 21 presents the results of a one way ANOVA conducted to examine whether preservice science teachers' PAI scale scores differed based on the urbanicity of their upbringing (city, district, or village). The findings show that the mean scores were 59.45 (SD = 7.64) for participants raised in cities, 59.22 (SD = 5.92) for those from districts, and 58.40 (SD = 6.24) for those from villages. The overall mean score across all groups was 59.23 (SD = 6.78). The ANOVA results yielded an F value of 0.014 with a significance level of  $p = .869$ , which is well above the conventional threshold of .05. This indicates that there were no statistically significant differences in PAI scale scores according to the urbanicity of upbringing.

Table 22.

*Descriptive Statistics of Preservice Science Teachers' PAI Scores by Type of Secondary School Graduated*

Type of Secondary School Graduated	N	$\bar{X}$	sd
Science High School	17	62,00	5,87

Anatolian High School	88	58,81	6,52
İmam Hatip High School	17	58,65	8,54
Total	122	59,23	6,78

Table 22 presents the descriptive statistics of preservice science teachers' PAI scale scores according to the type of secondary school graduated. The results show that the mean score of science high school graduates ( $X = 62.00$ ,  $SD = 5.87$ ) is higher compared to those from Anatolian High Schools ( $X = 58.81$ ,  $SD = 6.52$ ) and Imam Hatip High Schools ( $X = 58.65$ ,  $SD = 8.54$ ). The overall mean across all groups was 59.23 ( $SD = 6.78$ ).

Table 23.

*ANOVA Results of Preservice Teachers' PAI Scale Scores by Type of Secondary School Graduated*

PAI Scale		Sum of Squares	df	Mean Square	F	p	Post Hoc
Teaching perception	Between Groups	161,969	2	80,985	5.326	.006	1>2
	Within Groups	1809,309	119	15,204			
	Total	1971,279	121				
Learning perception	Between Groups	1,152	2	,576	.049	.952	
	Within Groups	1403,807	119	11,797			
	Total	1404,959	121				
Ethical perception	Between Groups	4,406	2	2,203	.442	.644	
	Within Groups	592,717	119	4,981			
	Total	597,123	121	80,985			
Total	Between Groups	151,976	2	75,988	1.670	.193	
	Within Groups	5415,598	119	45,509			
	Total	5567,574	121				

Table 23 presents the results of the one way ANOVA conducted to examine whether the differences among groups are statistically significant. The findings indicate that a significant difference was observed only in the TP sub-dimension of the PAI scale ( $F = 5.326$ ,  $p = .006$ ). This result suggests that the type of high school graduated has a statistically significant effect on preservice teachers' teaching perception scores. However, no significant differences were found in the learning perception ( $F = 0.049$ ,  $p = .952$ ), ethical perception ( $F = 0.442$ ,  $p = .644$ ), or total scale scores ( $F = 1.670$ ,  $p = .193$ ). In summary, while graduates of different high school types do not differ significantly in overall PAI scores or in most sub-dimensions, Science High School graduates tend to report higher scores in TP, and this difference reaches statistical significance. This finding may reflect the stronger academic orientation and science-focused curriculum of science high schools, which could positively influence preservice teachers' perceptions of teaching with respect to AI.

Table 24.

*Descriptive Statistics of Preservice Science Teachers' PAI Scale Scores by Daily Use of Technology*

Daily Use of Technology (e.g., Computers, etc.)	N	$\bar{X}$	sd
0-3 h	32	59,66	7,77
3-5 h	55	58,98	5,56
More than 5 h	35	59,23	7,70
Total	122	59,23	6,78

The table 24 presents the descriptive statistics of preservice teachers' PAI scale scores based on their daily use of technology (e.g., computers, etc.). The participants were divided into three groups: those using technology 0–3 hours ( $M = 59.66$ ,  $SD = 7.77$ ,  $N = 32$ ), 3–5 hours ( $M = 58.98$ ,  $SD = 5.56$ ,  $N = 55$ ), and more than 5 hours ( $M = 59.23$ ,  $SD = 7.70$ ,  $N = 35$ ). The total mean score across all groups was 59.23 ( $SD = 6.78$ ,  $N = 122$ ), suggesting a relatively consistent perception across different levels of daily technology use.

Table 25.

*ANOVA Results of Preservice Science Teachers' PAI Scale Subscale Scores by Daily Use of Technology*

PAI Scale		Sum of Squares	df	Mean Square	F	p	Post Hoc
Teaching perception	Between Groups	13,757	2	6,878	.418	.659	
	Within Groups	1957,522	119	16,450			
	Total	1971,279	121				
Learning perception	Between Groups	21,814	2	10,907	.938	.394	
	Within Groups	1383,145	119	11,623			
	Total	1404,959	121				
Ethical perception	Between Groups	47,952	2	23,976	5.195	.007	2>3
	Within Groups	549,171	119	4,615			
	Total	597,123	121				
Total	Between Groups	9,202	2	4,601	.099	.906	
	Within Groups	5558,372	119	46,709			
	Total	5567,574	121				

The table 25 provides the results of the ANOVA test conducted to determine whether the PAI subscale scores differed significantly based on daily technology use. The findings indicate no statistically significant differences for TP ( $F = 0.418$ ,  $p = .659$ ), LP ( $F = 0.938$ ,  $p = .394$ ), and the total scale ( $F = 0.099$ ,  $p = .906$ ). However, a significant difference was observed for the EP subscale ( $F = 5.195$ ,  $p = .007$ ), indicating that preservice science teachers' ethical perceptions regarding AI integration in education varied depending on their daily use of technology. Post-hoc comparisons revealed that the difference emerged particularly between the groups using technology 2–3 hours and those with higher usage levels.

Table 26.

*Descriptive Statistics of Preservice Science Teachers' PAI Scale Scores by Daily Internet Usage*

Daily Internet Usage (including via mobile phone)	N	$\bar{X}$	sd
0-3 h	29	58,76	7,46
3-5 h	56	58,88	5,99
More than 5 h	37	60,14	7,44
Total	122	59,23	6,78

The table 26 presents the descriptive statistics for preservice science teachers' PAI scale scores according to their daily internet usage, categorized as 0–3 hours, 3–5 hours, and more than 5 hours. The mean scores are relatively close across groups (58.76, 58.88, and 60.14, respectively), with standard deviations ranging from 5.98 to 7.46. This suggests that internet usage time does not lead to large differences in the overall distribution of PAI scores.

Table 27.

*ANOVA Results of Preservice Science Teachers' PAI Scale Scores by Daily Internet Usage*

PAI Scale		Sum of Squares	df	Mean Square	F	p	Post Hoc
Teaching perception	Between Groups	67,844	2	33,922	2.121	.124	
	Within Groups	1903,434	119	15,995			
	Total	1971,279	121				
Learning perception	Between Groups	,820	2	,410	.035	.966	
	Within Groups	1404,139	119	11,799			

	Total	1404,959	121				
Ethical perception	Between Groups	58,152	2	29,076	6.420	.002	3>2
	Within Groups	538,971	119	4,529			2>1
	Total	597,123	121				
Total	Between Groups	43,814	2	21,907	.472	.625	
	Within Groups	5523,760	119	46,418			
	Total	5567,574	121				

The table 27 reports the results of the ANOVA test conducted to examine differences across these groups for specific subdimensions of the PAI scale. The results show no statistically significant differences in teaching perception ( $F=2.121, p=.124$ ) or learning perception ( $F=.035, p=.966$ ). However, a significant difference was found in the ethical perception subscale ( $F=6.420, p=.002$ ). Post-hoc comparisons revealed that participants who reported using the internet more than 5 hours daily scored significantly higher in ethical perception compared to those in the 0-3 hour and 3-5 hour groups. The total scale scores, however, did not differ significantly across the groups ( $F=.472, p=.625$ ).

## 4. RESULTS, DISCUSSION AND RECOMMENDATIONS

### 4.1. Preservice Science Teachers' AI-TPACK Competencies

Preservice science teachers' AI-TPACK competency levels suggest that while they recognize the potential of AI in enhancing learning and professional growth, their relatively lower mean scores in areas such as frequent classroom use and domain specific applications reveal gaps in practical integration. Similarly, Bautista et al. (2024) reported that preservice teachers encountered challenges in transforming this knowledge into pedagogical practice despite demonstrating familiarity with AI based tools. Dogan et al. (2025) likewise emphasized that preservice teachers' AI-TPACK competencies remain particularly limited in practice-oriented contexts, showing a gap between technical proficiency and pedagogical application. Runge et al. (2025) further confirmed that preservice teachers' technical familiarity with AI does not automatically translate into pedagogically integrated practice. Oved & Alt (2025) also highlighted that preservice teachers' familiarity with AI remains technical mainly and does not translate into sustained pedagogical integration, reinforcing the need for practice-oriented approaches. This finding is also consistent with studies indicating that teachers holding constructivist beliefs are more inclined to adopt educational AI tools, and that perceptions of trust, usefulness, and ease of use play a decisive role in the adoption process (Abdelmoneim et al., 2024). Therefore, targeted training opportunities that emphasize hands-on, pedagogically integrated use of AI are essential to foster more comprehensive AI-TPACK competencies.

### 4.2. Preservice Science Teachers' Perceptions Regarding AI Use in Education

The findings highlight a dual perspective regarding preservice science teachers' perceptions of AI in education. On one hand, AI is recognized as a powerful tool for enhancing efficiency, providing rapid evaluation, and facilitating access to ready-made knowledge. On the other hand, concerns were raised about potential drawbacks such as reduced student engagement and dependency on AI systems. This dual perspective aligns with Bautista et al. (2024), who stressed that technological readiness must be accompanied by ethical awareness to prevent overreliance on AI. Dogan et al. (2025) similarly observed that while preservice teachers value AI's efficiency, they also recognize potential risks related to diminished student participation. Runge et al. (2025) reinforced this duality, noting that preservice teachers acknowledged AI's efficiency benefits but simultaneously expressed concerns about ethical risks and reduced learner engagement. Similarly, Spasopoulos, Sotiropoulos & Kalogiannakis (2025) found that while preservice science teachers valued AI for its efficiency in science instruction, they simultaneously voiced concerns over diminished learner autonomy and overdependence on automated systems. Preservice teachers' perception of AI as a tool that provides speed and convenience parallels findings from educational AI tool research, which emphasize that perceptions of usefulness and ease of use play a critical role in adoption (Abdelmoneim et al., 2024). This underscores the importance of integrating AI into teacher education with a balanced pedagogical approach that maximizes its instructional benefits while minimizing risks related to overdependence and superficial learning.

### 4.3. Relationship Between AI-TPACK Competencies and Perceptions of AI

This study's correlation between AI-TPACK and PAI scores highlights the interplay between preservice science teachers' technological pedagogical competencies and their perceptions of AI. This resonates with Bautista et al. (2024), who observed significant positive correlations between TPACK dimensions and ethical readiness, suggesting that competence and perception reinforce each other. In line with this, Dogan et al. (2025) also found that preservice teachers with higher AI-TPACK competencies exhibited more favorable perceptions of AI integration. Runge et al. (2025) confirmed these patterns, showing that preservice teachers with stronger AI-TPACK competencies consistently demonstrated more positive perceptions of AI in education. Similarly, Oved & Alt (2025) demonstrated that preservice teachers with stronger AI-TPACK skills not only felt more

competent but also expressed higher confidence in AI adoption, underscoring the reciprocal nature of competence and perception. This situation is further supported by findings indicating that teachers who use technology, attend AI related courses, and possess a background in science education demonstrate more favorable perceptions of and stronger intentions to adopt educational AI tools (Abdelmoneim et al., 2024). This finding suggests that teachers who feel more competent in integrating AI tend to also hold more positive attitudes toward its use in teaching and learning, underlining the mutually reinforcing nature of competence and perception in shaping future classroom practices.

#### 4.4. Differences in AI-TPACK Competencies According to Demographic Variables

Overall, these results suggest that male preservice science teachers in this sample generally perceive themselves as more competent in applying AI within technological, pedagogical, and content knowledge frameworks than female preservice teachers, with differences being particularly pronounced in CK, PK, TPACK, and overall, AI-TPACK scores.

Prior experience with technology assisted teaching does not appear to significantly influence preservice science teachers perceived competencies in AI-TPACK dimensions within this sample. Empirical studies on TPACK and 21st-century teaching competencies indicate that teaching experience alone is often an insignificant predictor once the quality of learning opportunities is considered. For example, Shafie et al. (2023) found that years of teaching did not significantly enhance teachers' 21st-century TPACK levels, emphasizing that continuous and structured professional development plays a more crucial role than mere experience. Similarly, Koh and Chai (2014) reported that TPACK development depends more on pedagogically grounded design experiences than on teaching tenure. In the specific case of AI integration, Alejandro et al. (2024) and Li et al. (2024) demonstrated that prior exposure to educational technologies or AI tools does not automatically lead to higher AI-TPACK competencies supported by explicit training and reflection. This finding suggests that initial exposure to technology assisted teaching may not necessarily translate into higher self perceived competence in AI-TPACK domains. One possible explanation is that the quality and depth of such experiences vary, and short term or limited exposure may not be sufficient to foster measurable differences in teachers' technological, pedagogical, and content knowledge related to AI integration.

The results also indicate that AI training enhances preservice science teachers' technological knowledge but does not necessarily translate into significant improvements in pedagogical or content-related dimensions. This conclusion is consistent with Bautista et al. (2024), who underscored the need for AI education to move beyond technical skills toward integrated pedagogical and ethical applications. Similarly, Dogan et al. (2025) pointed out that existing AI training programs primarily strengthen technical competencies, with limited impact on pedagogical or content knowledge. Spasopoulos et al. (2025) also confirmed this tendency in science education contexts, showing that AI related training courses strengthened technical proficiency while offering limited contributions to pedagogical or content knowledge integration. Abdelmoneim et al. (2024) demonstrated that teachers who participate in AI courses exhibit more favorable intentions to adopt educational AI tools. However, the present study indicates that short term training programs focus primarily on technical knowledge and show limited effectiveness in fostering pedagogical integration. Future research could explore whether more comprehensive and practice oriented AI training has a broader impact on preservice teachers' AI-TPACK competencies.

Across all dimensions of the AI-TPACK scale, no statistically significant differences were found between participants with prior training. This suggests that limited or basic exposure to software/programming may not be sufficient to yield meaningful improvements in preservice teachers' AI-TPACK competencies. Instead, the findings indicate that more structured, comprehensive, and pedagogically integrated training programs may be necessary to foster significant growth in both technical and pedagogical dimensions of AI-TPACK. In other words, while prior programming knowledge provides a slight advantage, it does not ensure higher competency levels in applying AI within pedagogical contexts.

The study found no significant differences in preservice teachers' AI-TPACK competencies across demographic variables such as class level, school type, or socio geographic background. This is consistent with Bautista et al. (2024), who reported that readiness for AI integration is shaped more by technological and pedagogical competencies than demographic characteristics. Dogan et al. (2025) also confirmed that gender or class level does not produce significant differences in AI-TPACK competencies. Runge et al. (2025) found that demographic factors such as gender, socio-economic status, or class level did not significantly affect preservice teachers' AI-TPACK outcomes. Oved & Alt (2025) reached a similar conclusion, reporting that demographic characteristics such as age, class level, and prior schooling background had no significant effect on preservice teachers' AI-TPACK competencies. Abdelmoneim et al. (2024) emphasized that teachers with a background in science education tend to hold more favorable perceptions of educational AI tools. However, the present study revealed that neither school type nor socio geographic factors produced significant differences. Future research could investigate whether contextual factors, such as the availability of digital infrastructure or exposure to technology during schooling, might moderate the relationship between upbringing context and AI-TPACK development.

The results indicate that preservice science teachers' AI-TPACK competencies are not significantly affected by the amount of their daily technology use. While those who reported moderate daily use (3–5 hours) showed slightly higher mean scores, this difference was not statistically meaningful. This suggests that the frequency of technology use alone does not guarantee stronger competencies. These findings emphasize the importance of how technology is used rather than how often it is used. Structured, purposeful, and pedagogically integrated training in teacher education programs appears to be more critical for developing AI-

TPACK competencies than the mere duration of exposure to technology. Future research could investigate the quality of technology use, such as the types of digital tools employed or the extent to which they are integrated into teaching practices, to understand better their role in shaping preservice teachers' competencies.

The duration of daily internet use, including mobile phone use, does not significantly influence preservice teachers' AI-TPACK competencies. Although moderate use (3–5 hours) is linked with slightly higher scores, the absence of statistical significance suggests that time spent online alone is insufficient for competency development. This highlights the importance of purposeful and pedagogically integrated internet use rather than the sheer quantity of use. Future research could examine the quality of online activities (e.g., educational vs. recreational use) to better understand their potential role in fostering AI-TPACK growth.

These results indicate that preservice science teachers' ability to integrate technological, pedagogical, and content knowledge with AI is linked to their attitudes toward AI in educational contexts. However, the relatively low correlation coefficient suggests that while AI-TPACK competencies may contribute to shaping perceptions of AI, other contextual or personal factors likely play a more substantial role. Future studies could explore additional variables, such as teaching experience, digital literacy, or exposure to AI applications, to better understand the factors influencing preservice teachers' perceptions of AI.

#### 4.5. Differences in Perceptions of AI Use in Education According to Demographic Variables

The analysis revealed no significant gender differences in preservice science teachers' perceptions of AI across the PAI scale and its subscales. Only in the ethical perception dimension did the results approach the significance threshold, with male participants reporting slightly higher scores. Overall, the findings suggest that gender is not a determining factor in shaping preservice science teachers' perceptions of AI in education. Nonetheless, the near significant difference in ethical perceptions points to a potential trend that may merit further exploration in future studies. This aligns with prior research demonstrating that demographic characteristics, including gender, have a limited impact on teachers' AI related perceptions, with attitudes being shaped more by pedagogical experiences and professional readiness than by personal background variables (Işık, Çakır & Korkmaz, 2024; Kotsis, 2025). Furthermore, the emerging emphasis on ethical sensitivity echoes findings highlighting ethics and responsibility as central aspects of teachers' AI perceptions (Alwaqdanı, 2025; Uygun, 2024).

The independent samples t-test results revealed that preservice teachers' prior experience with technology assisted teaching did not produce significant differences in their scores on the learning, ethical, or total dimensions. This indicates that prior experience with technology supported instruction does not strongly influence preservice science teachers' perceptions of AI in education. While such experience may foster familiarity with digital tools, it does not substantially shape attitudes toward AI within the pedagogical, learning, or ethical domains. These findings highlight the necessity of structured and targeted training specifically focused on AI in education, rather than relying solely on general technology experience. This interpretation resonates with Nissim & Simon (2025), who emphasized that perceptions of AI adoption are primarily driven by teachers' trust in its usefulness and pedagogical value, rather than by general technological familiarity.

The results showed that preservice science teachers with prior AI training reported slightly higher scores in teaching, learning, and overall perceptions. In contrast, those without training scored marginally higher in ethical perception. However, these differences were not statistically significant, indicating that prior AI training alone does not substantially influence preservice science teachers' views on AI in education. This suggests the importance of structured, targeted AI focused training to meaningfully shape preservice science teachers' perceptions. Similarly, recent studies indicate that while short term exposure to AI related courses may enhance awareness, more comprehensive, contextually embedded training is required to foster sustained changes in teachers' perceptions (Işık, et al. 2024; Uygun, 2024).

The findings indicate that prior training in software/programming did not significantly affect preservice science teachers' perceptions of AI in education. This suggests that general programming knowledge alone is insufficient, highlighting the need for targeted and AI-specific training. These results mirror those of Sanusi et al. (2024), who found that differences in national and institutional contexts strongly mediate AI perceptions, underscoring that broader experiences or technical backgrounds do not automatically translate into favorable or critical perspectives.

These findings imply that having prior exposure to software or programming training does not necessarily translate into higher AI-TPACK competency levels among preservice teachers. While such experience might enhance basic technical familiarity, it appears insufficient to significantly improve integrated pedagogical applications of AI. This highlights the importance of targeted AI-specific teacher education programs rather than relying solely on general programming experience.

The results showed no significant differences in preservice science teachers' PAI scores across class levels and the urbanicity of upbringing. Perceptions of AI in education appeared consistent among students from different academic years. This suggests that class level does not substantially influence preservice science teachers' attitudes toward AI, indicating a relatively stable perception regardless of progression in their program. Whether participants were raised in urban, semi-urban, or rural areas, their perceptions of AI in education remained consistent. This suggests that the upbringing context does not play a determining role in shaping preservice teachers' attitudes toward AI. This finding is consistent with broader international evidence

suggesting that perceptions of AI are not primarily determined by demographic or geographical background, but by contextual and pedagogical variables (Kotsis, 2025; Sanusi et al., 2024).

The findings show that preservice science teachers' PAI scores differed significantly only in the teaching perception subscale, with science high school graduates reporting higher scores than their peers. This suggests that a science oriented educational background may enhance perceptions of AI in teaching. However, no significant differences were found in learning, ethical, or overall scores, indicating that the impact of school type on AI perceptions is limited and context-specific. These results parallel the emphasis in Nissim & Simon (2025) that perceptions of AI's pedagogical utility are strengthened when teachers possess prior exposure to science-oriented epistemologies that prioritize systematic inquiry and technological integration.

The results suggest that the duration of daily technology use does not significantly influence preservice science teachers' general teaching and learning perceptions about AI. This indicates a degree of stability in their pedagogical and learning related attitudes toward AI regardless of technology engagement. In contrast, ethical perception is sensitive to technology usage levels, with significant differences between groups. This implies that individuals who use technology for longer durations may have more nuanced or critical perspectives on ethical issues related to AI applications in education, such as fairness, data privacy, and responsible use. While teaching and learning perceptions remain relatively stable across different levels of daily technology use, ethical considerations are more dynamic and likely shaped by personal exposure and engagement with digital technologies. This finding corresponds with Alwaqadani (2025) and Uygun (2024), who stressed that teachers' perceptions of AI often converge around ethical awareness, which becomes more salient with increased exposure to digital environments.

These findings indicate that daily internet usage does not directly impact preservice teachers' teaching or learning perceptions within the PAI framework. Nevertheless, heavy internet users (more than 5 hours per day) exhibit stronger ethical perceptions than their peers with lower internet usage. This result may imply that extended exposure to digital platforms enhances awareness and sensitivity toward ethical considerations, such as responsible technology use, digital literacy, and online behavior. However, the lack of significant differences in other subdimensions suggests that the influence of internet usage may be context specific rather than pervasive across all domains of pragmatic attitudes. This conclusion resonates with international studies noting that while digital exposure alone may not affect teachers' overall perceptions of AI, it tends to heighten sensitivity to fairness, privacy, and responsibility (Sanusi et al., 2024; Alwaqadani, 2025).

#### 4.6. Limitations and Recommendations for Future Research

This study relies on preservice science teachers' self-reported data, which may not fully capture their actual classroom practices, and its cross-sectional design limits the ability to observe changes in AI-TPACK competencies over time. Participants' AI-related training experiences were primarily short-term and technically oriented, restricting insights into the effects of more comprehensive, pedagogically integrated programs. Although demographic and experiential variables were examined, contextual factors such as institutional digital infrastructure and the quality of prior training were beyond the scope of this study.

#### Research and Publication Ethics Statement

The entire research process was conducted in strict accordance with established ethical standards. All data obtained from participants were utilized solely within the scope of the present study, and the reporting procedures adhered fully to recognized guidelines for research ethics.

#### Contribution Rates of Authors to the Article

The authors provide equal contributions to this work.

#### Statement of Interest

There is no conflict of interest.

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