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ARTIFICIAL INTELLIGENCE AWARENESS AND AI-TPACK AMONG SCIENCE TEACHERS IN TÜRKİYE

İsmail Satmaz

Abstract. *Artificial intelligence (AI) is changing how science is taught, and teachers need both an awareness of AI and the pedagogical knowledge to use it in class. This study examined the AI awareness and AI technological pedagogical content knowledge (AI-TPACK) of science teachers in Türkiye, compared these scores across demographic and professional groups, and analysed how the two constructs are related. In a cross-sectional correlational survey, data were gathered from 434 science teachers in state and private schools with the AI Awareness Scale for Science Teachers and the AI-TPACK Scale. Groups were compared with t-tests and Welch's ANOVA followed by Games–Howell tests, and relationships were examined with Pearson correlations. Teachers' AI awareness was at a moderate level, whereas their AI-TPACK was high. Scores varied by school type, AI training, years of experience, and degree level, while gender differences appeared in only a few subdimensions. Private-school teachers and teachers with AI training scored markedly higher on both scales. AI awareness correlated strongly with AI-TPACK, most clearly with its AI-related technological domains. As the data are cross-sectional, these patterns cannot be read causally, but they point to AI-specific professional learning and fair access to AI resources as priorities for science teacher education.*

Keywords: *artificial intelligence, AI awareness, AI-TPACK, science teachers, teacher professional development, science education*

İsmail Satmaz
Çanakkale Onsekiz Mart University, Türkiye

Introduction

Digital technologies keep reshaping schools and what is expected of teachers. AI tools such as intelligent tutoring systems, adaptive learning platforms, and generative AI open up new ways of teaching, yet they also bring pedagogical and ethical questions (Holmes & Miao, 2023). Science teachers therefore need to understand, judge, and use these tools within their own subject if they are to teach with AI effectively (Celik, 2023; Miao & Cukurova, 2024).

Mishra and Koehler (2006) proposed the Technological Pedagogical Content Knowledge (TPACK) framework, which describes teacher knowledge as the interplay of content, pedagogy, and technology. The framework is widely used in studies of technology integration because it shows how these types of knowledge combine when teachers teach with technology. As AI tools have become common in schools, researchers have adapted the model to AI. Ning et al. (2024) developed and validated the AI-TPACK construct, which refers to the knowledge teachers need to bring AI technologies together with subject matter and pedagogy. The model has three basic knowledge types, namely content knowledge (CK), pedagogical knowledge (PK), and AI technological knowledge (AI-TK), and four types that emerge where these overlap: pedagogical content knowledge (PCK), AI technological content knowledge (AI-TCK), AI technological pedagogical knowledge (AI-TPK), and AI-TPACK itself. Celik (2023) added an ethical layer in the Intelligent-TPACK framework, arguing that ethical judgement belongs at the centre of teachers' knowledge for AI use rather than at its margins. For science teachers, AI-TPACK can be taken to mean their perceived ability to use AI tools, for example to simulate phenomena or analyse experimental data, in ways that suit inquiry-based teaching of particular science topics. The four AI-related domains are thus the ones most directly tied to AI integration, while CK, PK, and PCK make up the traditional knowledge on which that integration rests.

AI awareness is the second construct examined here. It covers teachers' basic knowledge of AI, their recognition of how AI can be used in teaching, their sensitivity to ethical issues, their perception of risks, and their openness to AI at work (Özdemir & Benli Özdemir, 2025; Younis, 2025). UNESCO's

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competency framework for teachers adds that successful use of AI depends not only on technical and pedagogical skill but also on human-centred values, ethics, and the ability to judge AI outputs critically (Miao & Cukurova, 2024). Here, AI values denote the principles that should guide responsible use of AI in education, such as human agency, fairness, transparency, privacy, accountability, and concern for learners' well-being. These principles are closest to the Ethical Awareness and Risk Perception dimensions of AI awareness. Put simply, AI values give an ethical direction, AI awareness reflects a broad understanding and appraisal of AI, and AI-TPACK reflects perceived knowledge for integrating AI into teaching; the three can be seen as linked parts of teachers' readiness to teach with AI. Teachers who better understand what AI can and cannot do may also be better placed to judge and use AI tools, so higher awareness may go together with stronger AI-related knowledge. Awareness, however, is not the same as the ability to build AI into lessons, and the two constructs should be kept apart. Three links were therefore expected: (a) the knowledge and pedagogical application component of awareness would show the closest association with the AI-specific AI-TPACK domains; (b) the value-oriented components (Ethical Awareness and Risk Perception) would also relate to AI-TPACK, because responsible integration draws on AI values; and (c) awareness would relate only weakly to CK, PK, and PCK.

Science education raises its own questions about AI integration. AI-based data analysis tools let students work with large real-world datasets in biology, chemistry, physics, and earth science; simulation environments make phenomena that cannot be observed directly, such as molecular motion, ecosystem dynamics, or climate scenarios, visible in class; and adaptive assessment platforms can give students quick, individual feedback on their developing science concepts (Saimon et al., 2024). Science classrooms also raise epistemological problems. Since scientific knowledge rests on empirical evidence, teachers must help students approach AI critically: to separate AI-generated claims from scientifically supported conclusions, to keep inquiry authentic when AI tools are involved, and to think about data sources and algorithmic bias (Celik, 2023; Miao & Cukurova, 2024). General models of teacher AI competency may therefore fall short in science education, and subject-specific frameworks and instruments are required (Alshorman, 2024).

Studies on teachers' AI-TPACK have multiplied in recent years. In a survey of 1,664 K–12 teachers, Yue et al. (2024) found that teachers rated their pedagogical knowledge more highly than their AI-related content and technological knowledge, suggesting that subject-specific AI knowledge should be a focus of professional development. In Türkiye, Cindilli et al. (2026) studied 215 teachers in a cross-sectional design and found that AI-TPACK varied with AI training, educational level, and school type; teachers in private schools and teachers with AI training scored higher. Hava and Babayiğit (2025) likewise reported positive associations between Turkish teachers' AI-TPACK and their digital proficiency, which points to a link between general technological competence and AI-specific pedagogical knowledge.

Intervention studies indicate that well-designed learning experiences can strengthen teachers' AI competencies. In Ding et al. (2024), teachers who analysed a range of AI classroom cases during professional development reported improved AI literacy and integration strategies. Moorhouse et al. (2024) documented significant gains in pre-service language teachers' generative AI pedagogical competence and critical awareness following an 11-week intervention. Saimon et al. (2024) similarly reported that a design-based learning approach incorporating lesson planning, micro-teaching, peer feedback, and reflection cycles supported student teachers in developing AI integration competencies. These studies point to the importance of the format, depth, and continuity of AI-related professional development for developing these competencies.

In Türkiye, recent curriculum reforms have brought AI literacy and computational thinking to the forefront of national education policy, with the Ministry of National Education progressively embedding AI-related objectives into science, technology, and mathematics curricula (Özdemir & Benli Özdemir, 2025). However, systematic professional development opportunities for AI integration in science teaching remain limited at the national level, and the AI competencies of science teachers have received relatively limited empirical attention compared with those of teachers in fields such as mathematics or information technology. Science teachers in Türkiye work in both state and private schools, which may differ in their access to digital resources and training, and they are now expected to use technology and AI in their lessons. Yet evidence on how ready these teachers are for AI integration is still limited (Hava & Babayiğit, 2025). This makes Türkiye a useful setting for examining science teachers' AI awareness and AI-TPACK.

Several gaps are still evident in this literature. First, AI awareness and AI-TPACK have rarely been measured together in one sample, which leaves the relationship between these two constructs underexplored. Second, science teachers, whose work involves data interpretation, scientific reasoning, inquiry, and the responsible use of evidence, have received limited targeted attention in AI competency research. Third, much of the existing research

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has been conducted in East Asian or Western contexts, while Türkiye represents a distinct sociocultural and institutional context in which digitalization policies and ongoing educational reforms form the context of teachers' engagement with AI (Cindilli et al., 2026; Özdemir & Benli Özdemir, 2025).

To address these gaps, the present study focuses on science teachers in Türkiye. It describes their AI awareness and AI-TPACK, compares these scores by gender, years of experience, degree level, school type, and AI training, and tests how closely the two constructs are related, in order to clarify whether they are distinct but connected components of teachers' AI competency.

Research Aim and Research Questions

The study had three aims: to describe science teachers' levels of AI awareness and AI-TPACK, to test whether these levels vary with gender, professional experience, educational attainment, school type, and AI-related training, and to examine how the two constructs are related. The research questions were as follows:

1. What levels of AI awareness and AI-TPACK do science teachers report?
2. Do AI awareness and AI-TPACK scores vary significantly by gender, professional experience, educational attainment, school type, and AI-related training status?
3. Is AI awareness significantly related to AI-TPACK among science teachers?

Research Methodology

Design

A quantitative survey design that was both cross-sectional and correlational was used. Such a design collects data from a defined group at a single time point and examines relationships among variables without manipulating them (Creswell & Creswell, 2017; Fraenkel et al., 2012). The study therefore described teachers' AI awareness and AI-TPACK scores, compared them across demographic and professional groups, and analysed how the two constructs are related. Data were gathered online in July 2026, at the close of the 2025–2026 academic year, following approval by the Çanakkale Onsekiz Mart University Social and Human Sciences Ethics Committee (decision dated 10 July 2026, No. 24/86).

Participants

The study targeted science teachers working in state and private schools under the Ministry of National Education in Türkiye. Because official statistics do not break teacher numbers down by subject, the exact size of this population is unknown; the latest published figures show that 1,187,409 teachers were employed in formal education in the 2024–2025 academic year (Ministry of National Education, 2025). Teachers who were accessible and willing to take part were recruited through convenience sampling (Etikan et al., 2016).

In total, 434 science teachers from various regions of Türkiye filled in the online questionnaire, and all of them formed the final sample. No target sample size was set beforehand: the questionnaire link was distributed via teacher networks and social media groups (e.g., WhatsApp and Facebook groups of science teachers), and every teacher who responded within the data collection period was included. Sensitivity power analyses, reported below, were then used to check whether the sample was large enough.

Of the 434 teachers, 280 were female and 154 male. Regarding education, 252 had a bachelor's degree, 119 a master's degree, and 63 a doctorate. Most taught in state schools ($n = 294$) rather than private schools ($n = 140$), and 175 had attended AI-related training while 259 had not. Teaching experience was grouped into five bands, from 0–5 years to 21 years or more. Table 1 summarizes these characteristics.

To judge sample adequacy, sensitivity power analyses were run for the planned tests (Cohen, 1988; Faul et al., 2009). With a two-tailed α of .05 and power set at .80, 434 participants allowed small correlations ($r \approx .13$), small-to-moderate differences between two groups ($d \approx .27–.29$), and small overall effects in Welch ANOVA ($f \approx .15–.17$) to be detected. The sample was thus regarded as sufficient for every analysis.

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Table 1
Demographic Characteristics of Participants

Variable	Category	*n*	%
Gender	Female	280	64.5
	Male	154	35.5
Professional experience	0–5 years	70	16.1
	6–10 years	84	19.4
	11–15 years	140	32.3
	16–20 years	42	9.7
	21 years and above	98	22.6
Educational attainment	Undergraduate	252	58.1
	Master's degree	119	27.4
	Doctoral degree	63	14.5
School type	State school	294	67.7
	Private school	140	32.3
AI-related training	Received AI training	175	40.3
	No AI training	259	59.7

Note. Percentages are based on $N = 434$.

Instruments

The data collection tools were a personal information form prepared by the researcher and two scales, the AI Awareness Scale for Science Teachers and the AI-TPACK Scale.

Personal Information Form

This five-item form asked about gender, years of teaching experience, highest degree, school type, and whether the teacher had attended any AI-related training.

AI Awareness Scale for Science Teachers

Özdemir and Benli Özdemir (2025) developed this scale to measure how aware science teachers are of AI. Its 29 items are answered on a 5-point Likert-type format and form five subscales: Knowledge and Pedagogical Application Awareness (11 items), Ethical Awareness in AI Use (5 items), Risk Perception and Concerns About AI (5 items), Perceived Contribution of AI to Student Skills (4 items), and Attitudes Toward and Acceptance of AI (4 items).

In the development study, confirmatory factor analysis confirmed the five-factor structure, and Cronbach's alpha for the whole scale was .867 (Özdemir & Benli Özdemir, 2025). Here, the negatively worded Risk Perception and Concerns items were reverse-coded before scores were computed, so a higher score on this subscale means less agreement with statements about AI risks and concerns. Internal consistency in the current sample was .884 for the full scale and between .787 and .943 for the subscales.

AI-TPACK Scale

Ning et al. (2024) developed this scale, and Canbazoğlu Bilici et al. (2024) adapted it to Turkish. It assesses how competent teachers believe they are at combining AI technologies with content and pedagogy.

Its 39 items, rated on a 5-point Likert-type format, belong to seven subscales: CK (5 items), PK (6 items), AI-TK (5 items), PCK (6 items), AI-TCK (6 items), AI-TPK (6 items), and AI-TPACK (5 items).

The Turkish adaptation confirmed the seven-factor structure and reported a total-scale alpha of .980 (Canbazoğlu Bilici et al., 2024). In the current sample, alpha was .945 for the total scale and .782–.938 for the subscales.

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Data Analysis

Coding, score ranges, and missing values were checked first; there were no missing responses. Items 17–21 of the AI Awareness Scale were reverse-coded prior to computing subscale and total scores, and reliability was estimated with Cronbach's alpha (Cronbach, 1951).

Frequencies and percentages described the sample. For the scale and subscale scores, means, standard deviations, minimum and maximum values, skewness, and kurtosis were computed. Whether the distributions suited parametric testing was judged from skewness and kurtosis in light of group sizes (Field, 2018; Tabachnick & Fidell, 2019).

Gender, school type, and AI training groups were compared with independent-samples *t*-tests. Where Levene's test showed unequal variances, Welch's *t*-test with adjusted degrees of freedom was used. Effect sizes were expressed as Cohen's *d* (Cohen, 1988).

Professional experience and educational attainment involve more than two groups. Since variances were not homogeneous, these comparisons used Welch's ANOVA, and significant results were followed by Games–Howell pairwise tests (Field, 2018).

Relationships between the total and subscale scores of the two scales were tested with Pearson correlations. All tests were two-tailed with α = .05, and correlations and *d* values were interpreted using Cohen's (1988) benchmarks.

Research Results

Preliminary Analyses and Descriptive Results

Before the main analyses, the data were checked against the assumptions of parametric tests. All skewness and kurtosis values lay between −1.5 and +1.5, so the score distributions were treated as approximately normal, and *t*-tests, Welch ANOVA, Games–Howell comparisons, and Pearson correlations were used.

Table 2 reports descriptive statistics and reliability coefficients for both scales.

Table 2
Descriptive Results and Reliability Coefficients for AI Awareness and AI-TPACK Scales

Scale	Subscale	Min	Max	M	SD	α
AI Awareness Scale	Knowledge and Pedagogical Application	13	51	34.29	9.21	.943
	Ethical Awareness	10	25	20.66	3.79	.871
	Risk Perception and Concerns1	5	18	11.82	3.11	.787
	Perceived Contribution to Student Skills	8	20	14.77	3.05	.794
	Attitudes Toward and Acceptance of AI	11	20	16.79	2.39	.811
	Total	65	122	98.34	13.36	.884
AI-TPACK Scale	Content Knowledge (CK)	14	25	20.48	2.97	.782
	Pedagogical Knowledge (PK)	16	30	24.82	4.09	.887
	AI Technological Knowledge (AI-TK)	5	25	17.23	4.58	.922
	Pedagogical Content Knowledge (PCK)	16	30	25.58	3.65	.861
	AI Technological Content Knowledge (AI-TCK)	12	30	20.84	5.16	.919
	AI Technological Pedagogical Knowledge (AI-TPK)	12	28	21.29	4.60	.938
	AI Technological Pedagogical Content Knowledge (AI-TPACK)	7	25	17.77	3.90	.874
	Total	106	190	148.02	20.19	.945

Note. M = mean; *SD* = standard deviation; α = Cronbach's alpha. Possible ranges are 29–145 for the 29-item AI Awareness scale and 39–195 for the 39-item AI-TPACK scale. Splitting each range into three equal intervals gives the following levels: AI Awareness, low 29.00–67.67, moderate 67.68–106.34, high 106.35–145.00; AI-TPACK, low 39.00–91.00, moderate 91.01–143.00, high 143.01–195.00. [1]Reverse-scored; higher values mean less perceived risk and concern.

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Using the levels given in the table note, teachers' mean AI Awareness total (M = 98.34, SD = 13.36) fell in the moderate range and their mean AI-TPACK total (M = 148.02, SD = 20.19) in the high range. Because subscales differ in item number and score range, their raw totals cannot be compared directly. Dividing each subscale mean by its number of items places all scores on the 1–5 response scale. On this basis, CK (4.10), PK (4.14), and PCK (4.26) were higher than AI-TK (3.45), AI-TCK (3.47), AI-TPK (3.55), and AI-TPACK (3.55). Among the awareness subscales, Attitudes Toward and Acceptance of AI (4.20) and Ethical Awareness (4.13) had the highest item means and Knowledge and Pedagogical Application (3.12) the lowest. The reverse-scored Risk Perception and Concerns subscale had a low item mean (2.36), which points to a fairly high level of concern about AI.

Gender Differences

Table 3 presents the comparisons by gender.

Table 3
Comparison of AI Awareness and AI-TPACK Scores by Gender

Scale	Subscale	Female (n = 280)		Male (n = 154)		t	df	p	d
		M	*SD*	*M*	*SD*				
AI Awareness	Knowledge and Pedagogical Application	34.73	9.23	33.50	9.14	1.327	432	.185	0.13
	Ethical Awareness	21.38	3.79	19.36	3.44	5.465	432	< .001	0.55
	Risk Perception and Concerns[1]	11.43	3.28	12.55	2.61	−3.891	377.69	< .001	−0.37
	Perceived Contribution to Student Skills	14.62	3.42	15.05	2.19	−1.556	422.27	.121	−0.14
	Attitudes Toward and Acceptance of AI	16.68	2.67	17.00	1.76	−1.520	417.95	.129	−0.14
	Total	98.83	14.30	97.45	11.29	1.096	381.09	.274	0.10
AI-TPACK	Content Knowledge (CK)	20.60	2.90	20.27	3.09	1.099	432	.272	0.11
	Pedagogical Knowledge (PK)	25.30	3.94	23.95	4.23	3.316	432	< .001	0.33
	AI Technological Knowledge (AI-TK)	17.40	4.56	16.91	4.62	1.064	312.13	.288	0.11
	Pedagogical Content Knowledge (PCK)	25.62	3.86	25.50	3.23	0.341	432	.733	0.03
	AI Technological Content Knowledge (AI-TCK)	20.98	5.36	20.59	4.76	0.768	348.21	.443	0.07
	AI Technological Pedagogical Knowledge (AI-TPK)	21.10	5.09	21.64	3.52	−1.289	409.94	.198	−0.12
	AI Technological Pedagogical Content Knowledge (AI-TPACK)	17.77	4.31	17.77	3.04	0.006	406.25	.995	0.00
	Total	148.78	20.90	146.64	18.64	1.093	347.99	.275	0.11

Note. Welch's t-test with adjusted df is reported where variances were unequal. d = Cohen's d. [1]Reverse-scored subscale.

Table 3 shows no gender difference in the total score of either scale. Only three dimensions differed. Female teachers scored higher on Ethical Awareness (d = 0.55) and Pedagogical Knowledge (d = 0.33) and lower on the reverse-scored Risk Perception and Concerns subscale (d = −0.37), meaning that they reported more AI-related risk and concern. The remaining dimensions did not differ by gender.

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School Type Differences

Table 4 shows the comparisons by school type.

Table 4
Comparison of AI Awareness and AI-TPACK Scores by School Type

Scale	Subscale	State School (n = 294)		Private School (n = 140)		t	df	p	d
		M	*SD*	*M*	*SD*				
AI Awareness	Knowledge and Pedagogical Application	31.02	8.41	41.15	6.70	−13.512	335.91	< .001	−1.28
	Ethical Awareness	19.93	4.25	22.20	1.78	−7.834	426.85	< .001	−0.62
	Risk Perception and Concerns[1]	12.98	2.80	9.40	2.21	14.433	338.55	< .001	1.36
	Perceived Contribution to Student Skills	14.38	2.87	15.60	3.26	−3.960	432	< .001	−0.41
	Attitudes Toward and Acceptance of AI	16.29	2.58	17.85	1.46	−8.031	419.20	< .001	−0.69
	Total	94.60	13.56	106.20	8.72	−10.732	394.93	< .001	−0.95
AI-TPACK	Content Knowledge (CK)	20.29	2.81	20.90	3.25	−2.022	432	.044	−0.21
	Pedagogical Knowledge (PK)	24.52	3.98	25.45	4.25	−2.215	432	.027	−0.23
	AI Technological Knowledge (AI-TK)	15.67	4.31	20.50	3.21	−13.063	355.41	< .001	−1.21
	Pedagogical Content Knowledge (PCK)	25.33	3.67	26.10	3.56	−2.076	280.96	.039	−0.21
	AI Technological Content Knowledge (AI-TCK)	19.19	4.69	24.30	4.32	−11.204	294.87	< .001	−1.12
	AI Technological Pedagogical Knowledge (AI-TPK)	19.64	4.63	24.75	1.74	−16.633	415.27	< .001	−1.30
	AI Technological Pedagogical Content Knowledge (AI-TPACK)	16.57	3.93	20.30	2.33	−12.330	411.64	< .001	−1.07
	Total	141.21	19.06	162.30	14.16	−12.909	356.43	< .001	−1.20

Note. Welch's correction was applied where variances were unequal. d = Cohen's d. [1]Reverse-scored subscale.

Private-school teachers had higher total AI Awareness and AI-TPACK scores than state-school teachers, and both differences were large (Table 4). Every dimension of the two scales differed between the groups. On the reverse-scored Risk Perception and Concerns subscale, private-school teachers scored lower, that is, they expressed more concern about AI. In AI-TPACK, the gaps were widest in the AI-related technological domains and small in CK, PK, and PCK.

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AI Training Status Differences

Table 5 compares teachers with and without AI-related training.

Table 5
Comparison of AI Awareness and AI-TPACK Scores by AI Training Status

Scale	Subscale	Received AI Training (n = 175)		No AI Training (n = 259)		t	df	p	d
		M	*SD*	*M*	*SD*				
AI Awareness	Knowledge and Pedagogical Application	40.92	7.99	29.81	7.02	15.292	432	< .001	1.50
	Ethical Awareness	21.96	2.62	19.78	4.19	6.653	429.75	< .001	0.60
	Risk Perception and Concerns[1]	10.96	2.94	12.41	3.09	−4.878	432	< .001	−0.48
	Perceived Contribution to Student Skills	15.24	3.16	14.46	2.93	2.635	432	.009	0.26
	Attitudes Toward and Acceptance of AI	17.28	2.53	16.46	2.24	3.551	432	< .001	0.35
	Total	106.36	13.50	92.92	10.17	11.816	432	< .001	1.16
AI-TPACK	Content Knowledge (CK)	20.48	3.21	20.49	2.80	−0.022	338.62	.983	0.00
	Pedagogical Knowledge (PK)	24.76	3.96	24.86	4.18	−0.262	432	.794	−0.03
	AI Technological Knowledge (AI-TK)	19.60	3.86	15.62	4.34	10.021	400.80	< .001	0.96
	Pedagogical Content Knowledge (PCK)	25.88	3.38	25.38	3.81	1.439	401.15	.151	0.14
	AI Technological Content Knowledge (AI-TCK)	24.24	4.23	18.54	4.41	13.543	383.59	< .001	1.31
	AI Technological Pedagogical Knowledge (AI-TPK)	23.56	3.36	19.76	4.70	9.835	430.61	< .001	0.90
	AI Technological Pedagogical Content Knowledge (AI-TPACK)	20.04	3.09	16.24	3.65	11.668	410.71	< .001	1.11
	Total	158.56	16.33	140.89	19.44	10.230	412.00	< .001	0.97

Note. Welch's correction was applied where variances were unequal. d = Cohen's d. [1]Reverse-scored subscale.

Teachers with AI-related training scored higher than untrained teachers on both total scores, again with large differences (Table 5). They also had lower scores on the reverse-scored Risk Perception and Concerns subscale (d = −0.48), indicating more concern. In AI-TPACK, the differences lay in the AI-specific domains, especially AI-TCK and AI-TPACK, whereas CK, PK, and PCK did not differ.

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Professional Experience Differences

Welch ANOVA results for AI Awareness across the experience groups are given in Table 6.

Table 6
Comparison of AI Awareness Scores by Professional Experience

Subscale	0–5 years		6–10 years		11–15 years		16–20 years		21 years and above		Welch's			Games-Howell
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*	
Knowledge and Pedagogical Application	37.40	6.33	36.25	8.21	32.95	9.16	26.33	10.71	35.71	9.01	11.66	4,168.81	< .001	1 > 3, 4; 2 > 3, 4; 3 > 4; 5 > 4
Ethical Awareness	22.30	2.21	19.00	3.85	20.95	3.92	18.17	5.21	21.57	2.54	15.21	4,166.32	< .001	1 > 2, 3, 4; 3 > 2, 4; 5 > 2, 4
Risk Perception and Concerns[1]	10.00	1.96	12.58	2.34	12.00	3.58	13.67	2.59	11.43	3.15	22.25	4,175.87	< .001	2, 3, 4, 5 > 1; 2 > 5; 4 > 3, 5
Perceived Contribution to Student Skills	15.50	2.44	15.08	2.71	15.35	3.18	15.50	1.27	12.86	3.31	12.84	4,194.00	< .001	1, 2, 3, 4 > 5
Attitudes Toward and Acceptance of AI	16.90	1.88	15.67	2.07	17.95	1.92	17.00	3.41	15.93	2.33	21.99	4,162.24	< .001	1 > 2, 5; 3 > 1, 2, 5
Total AI Awareness	102.10	8.92	98.58	11.85	99.20	11.06	90.67	17.60	97.50	16.62	4.56	4,164.59	.002	1 > 4; 3 > 4

Note. Groups: 1 = 0–5 years (n = 70), 2 = 6–10 years (n = 84), 3 = 11–15 years (n = 140), 4 = 16–20 years (n = 42), 5 = 21+ years (n = 98). Welch's ANOVA was used owing to unequal variances; the Games–Howell differences listed are significant at $p < .05$.
[1]Reverse-scored subscale.

AI Awareness varied significantly with professional experience (Table 6). The most consistent finding concerned teachers with 16–20 years in the profession, who scored lower on the total scale and on several dimensions. The other differences depended on the dimension, so the link between experience and awareness was not linear.

Table 7 gives the corresponding results for AI-TPACK.

Table 7
Comparison of AI-TPACK Scores by Professional Experience

Subscale	0–5 years		6–10 years		11–15 years		16–20 years		21 years and above		Welch's			Games-Howell
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*	
Content Knowledge (CK)	19.50	3.47	18.75	2.06	21.00	2.73	18.17	2.14	22.93	1.59	81.88	4,166.71	< .001	3 > 1, 2, 4; 5 > 1, 2, 3, 4
Pedagogical Knowledge (PK)	23.90	5.18	22.58	2.58	25.55	3.50	22.00	4.78	27.57	2.27	53.57	4,160.65	< .001	5 > 1, 2, 3, 4; 3 > 2, 4
AI Technological Knowledge (AI-TK)	19.30	4.10	17.67	4.13	17.15	4.10	13.17	6.08	17.21	4.11	8.97	4,163.62	< .001	1 > 3, 4, 5; 2, 3, 5 > 4
Pedagogical Content Knowledge (PCK)	24.90	4.35	23.50	2.95	26.30	3.39	22.17	1.79	28.29	1.84	100.92	4,174.40	< .001	1 > 4; 3 > 2, 4; 5 > 1, 2, 3, 4; 2 > 4
AI Technological Content Knowledge (AI-TCK)	22.90	3.96	22.17	4.06	20.55	5.26	18.50	4.95	19.64	5.91	9.66	4,171.57	< .001	1 > 3, 4, 5; 2 > 4, 5

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Subscale	0–5 years		6–10 years		11–15 years		16–20 years		21 years and above		Welch's			Games-Howell
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*	
AI Technological Pedagogical Knowledge (AI-TPK)	23.30	3.49	22.75	2.88	20.60	5.18	18.83	4.47	20.64	4.83	13.27	4,171.19	< .001	1, 2 > 3, 4, 5
AI Technological Pedagogical Content Knowledge (AI-TPACK)	19.40	1.12	18.92	2.74	17.10	4.83	15.83	4.02	17.43	3.87	17.76	4,165.78	< .001	1, 2 > 3, 4, 5
Total AI-TPACK	153.20	12.72	146.33	17.33	148.25	20.70	128.67	25.11	153.71	18.71	10.65	4,168.78	< .001	1 > 2, 4; 2, 3, 5 > 4; 5 > 2

Note. Groups: 1 = 0–5 years (n = 70), 2 = 6–10 years (n = 84), 3 = 11–15 years (n = 140), 4 = 16–20 years (n = 42), 5 = 21+ years (n = 98). Welch's ANOVA was used owing to unequal variances; the Games–Howell differences listed are significant at $p < .05$.

AI-TPACK also differed by experience (Table 7). Teachers with 21 or more years scored higher in the traditional content and pedagogical domains, those with up to 5 years scored higher in several AI-related domains, and those with 16–20 years had the lowest scores in many domains.

Educational Attainment Differences

Table 8 shows the results by educational attainment.

Table 8
Comparison of AI Awareness and AI-TPACK Scores by Educational Attainment

Scale	Subscale	U		M		D		Welch's			Games-Howell
		M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*	
AI Awareness	Knowledge and Pedagogical Application	32.94	9.66	37.29	8.79	34.00	6.48	9.39	2,184.49	< .001	M > U; M > D
	Ethical Awareness	19.92	4.38	21.65	2.62	21.78	2.06	14.99	2,212.79	< .001	M > U; D > U
	Risk Perception and Concerns[1]	11.94	3.42	11.94	2.61	11.11	2.53	2.70	2,177.37	.070	—
	Perceived Contribution to Student Skills	14.50	3.18	15.35	2.67	14.78	3.07	3.64	2,161.29	.029	M > U
	Attitudes Toward and Acceptance of AI	16.64	2.74	16.94	2.02	17.11	1.30	2.00	2,215.92	.138	—
	Total	95.94	14.68	103.18	11.30	98.78	7.88	13.57	2,204.33	< .001	M > U; M > D

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Scale	Subscale	U		M		D		Welch's			Games-Howell
		M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*	
AI-TPACK	Content Knowledge (CK)	20.11	3.14	20.24	2.81	22.44	1.43	45.61	2,219.45	< .001	D > U, M
	Pedagogical Knowledge (PK)	24.53	4.61	24.82	3.65	26.00	1.96	8.50	2,226.31	< .001	D > U, M
	AI Technological Knowledge (AI-TK)	16.25	4.95	18.88	3.53	18.00	3.74	17.53	2,175.77	< .001	M > U; D > U
	Pedagogical Content Knowledge (PCK)	25.31	4.24	25.47	2.95	26.89	1.30	18.03	2,250.18	< .001	D > U, M
	AI Technological Content Knowledge (AI-TCK)	20.00	5.18	22.71	4.37	20.67	5.58	13.82	2,156.30	< .001	M > U, D
	AI Technological Pedagogical Knowledge (AI-TPK)	20.11	4.72	22.41	3.53	23.89	4.37	24.21	2,164.09	< .001	M > U; D > U
	AI Technological Pedagogical Content Knowledge (AI-TPACK)	17.14	4.19	19.18	2.91	17.67	3.74	15.16	2,165.92	< .001	M > U, D
	Total	143.44	21.69	153.71	16.64	155.56	14.52	18.98	2,184.94	< .001	M > U; D > U

Note. U = undergraduate; M = master's degree; D = doctoral degree. Welch's ANOVA was used owing to unequal variances; the Games–Howell differences listed are significant at $p < .05$. [1]Reverse-scored subscale.

Degree level was related to several AI Awareness dimensions and to every AI-TPACK dimension (Table 8). Teachers holding a postgraduate degree usually scored above those with a bachelor's degree, but the pattern varied by dimension: master's graduates tended to score higher in several AI-specific domains, and doctoral graduates in the traditional content and pedagogical domains.

Relationships Between AI Awareness and AI-TPACK

Table 9 shows the correlations between the dimensions of the two scales.

Table 9
Pearson Correlations Between AI Awareness Subscales and AI-TPACK Subscales

AI Awareness Dimension	CK	PK	AI-TK	PCK	AI-TCK	AI-TPK	AI-TPACK	Total AI-TPACK
Knowledge and Pedagogical Application	.121*	.169***	.895***	.094	.845***	.737***	.794***	.809***
Ethical Awareness	.438***	.362***	.462***	.426***	.465***	.513***	.594***	.670***
Risk Perception and Concerns[1]	−.157**	−.182***	−.537***	−.096*	−.401***	−.315***	−.369***	−.445***
Perceived Contribution to Student Skills	−.099*	−.082	.508***	−.086	.517***	.428***	.308***	.358***
Attitudes Toward and Acceptance of AI	.217***	.127**	.312***	.203***	.444***	.459***	.391***	.459***
Total AI Awareness	.187***	.181***	.795***	.180***	.818***	.760***	.770***	.808***

Note. $N = 434$. See Table 2 for abbreviations. [1]Reverse-scored subscale. *$p < .05$. **$p < .01$. ***$p < .001$.

Total AI Awareness correlated positively with total AI-TPACK and with each of its dimensions (Table 9), most strongly with AI-TCK, AI-TK, AI-TPACK, and AI-TPK. Of the awareness dimensions, Knowledge and Pedagogical Application had the highest correlations with the AI-related domains, and Ethical Awareness and Attitudes Toward and Acceptance of AI were also positively correlated with several domains. Total awareness correlated only weakly with

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CK, PK, and PCK (r = .18–.19), against .76–.82 for the AI-specific domains. Risk Perception and Concerns correlated negatively with every AI-TPACK dimension; since this subscale is reverse-scored, higher AI-TPACK went together with more concern about AI. These are relationships only and say nothing about direction.

Discussion

The findings are interpreted as descriptive group differences and relationships consistent with the cross-sectional correlational design. Science teachers reported moderate AI awareness and high AI-TPACK; AI awareness was strongly associated with AI-TPACK; and differences were observed across school type, AI-related training, professional experience, and educational attainment. These patterns identify variables that co-occur with AI-related competencies in this sample but do not establish causal or explanatory relationships.

Because both measures are self-reported and were collected at one point in time, the contrast between moderate AI awareness and high AI-TPACK should be interpreted descriptively rather than as evidence that one form of competence develops before another. The pattern nevertheless points to a distinction between broader conceptual and ethical awareness of AI and perceived competence for integrating AI with pedagogy and content. This distinction is consistent with frameworks that treat responsible AI use as involving both integration knowledge and critical, human-centered understanding (Holmes & Miao, 2023; Miao & Cukurova, 2024). It should also be noted that the high total AI-TPACK score mainly reflected the traditional CK, PK, and PCK domains; the item means for the AI-specific domains (3.45–3.55) were clearly lower.

Ethical Awareness was comparatively high, while Knowledge and Pedagogical Application was lower. This descriptive pattern is compatible with the possibility that teachers recognize ethical issues surrounding AI even when their knowledge of classroom applications is less developed; however, the study did not test developmental sequencing. In terms of AI values, the relatively high Ethical Awareness scores and the considerable level of reported concern are consistent with teachers endorsing value-oriented considerations such as fairness, privacy, and transparency. Within AI-TPACK, traditional pedagogical knowledge was stronger than several AI-specific technological dimensions. Together, these results identify conceptual, ethical, and AI-specific technological knowledge as distinct areas that teacher education can address without assuming that one causes the other (Erdogan et al., 2026; Miao & Cukurova , 2024; Younis, 2025).

AI awareness and AI-TPACK were closely linked, with a correlation of r = .808 between the two total scores. The strongest relationships involved the Knowledge and Pedagogical Application dimension of AI awareness and the AI-related technological dimensions of AI-TPACK. This pattern is in line with the expected links: the application-oriented component of awareness was most closely related to the AI-specific domains, whereas relationships with CK, PK, and PCK were weak. The findings therefore indicate that the two constructs are closely related but not interchangeable. Earlier work has likewise linked AI-TPACK with AI literacy, digital competence, and technology acceptance (Hava & Babayiğit, 2025; Ning et al., 2024; Yue et al., 2024). Because the data are correlational, it is not possible to say which variable influences the other. The findings suggest that AI awareness and AI-TPACK are best viewed as related dimensions of professional readiness for AI-supported teaching. The negative correlations between the reverse-scored Risk Perception and Concerns subscale and AI-TPACK indicate that teachers with stronger perceived integration knowledge also reported more concern about AI. This fits Celik's (2023) Intelligent-TPACK argument that ethical and value-oriented awareness is part of, not an obstacle to, competent AI integration; this interpretation, however, was not tested directly.

AI-Related Training and AI Competencies

Teachers with prior AI-related training scored higher on both AI awareness and AI-TPACK than teachers without such training. The largest gaps were in Knowledge and Pedagogical Application (d = 1.50), AI-TCK (d = 1.31), and AI-TPACK (d = 1.11).

Training-related differences were larger than gender differences and were concentrated in the AI-specific dimensions. Intervention studies have shown that structured professional learning can raise teachers' AI literacy and AI-related pedagogical competence (Ding et al., 2024; Moorhouse et al., 2024), and Miao and Cukurova (2024) treat systematic professional learning as central to preparing teachers for AI. The present cross-sectional data cannot show that training produced the differences, but they do show that trained and untrained teachers differed considerably in several AI-specific competencies.

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The absence of training-related differences in CK, PK, and PCK, together with large differences in the AI-specific domains, fits the structure of AI-TPACK: AI-related training would be expected to relate mainly to the AI-specific layer of teacher knowledge rather than to the traditional content and pedagogical base.

For science teacher education, this pattern supports greater attention to AI-specific professional learning. Since the AI-specific domains, including AI-TK and AI-TCK, showed the widest gaps, such programs could give priority to hands-on work with AI tools in science-specific tasks, such as analysing experimental data, running AI-supported simulations, and checking AI-generated explanations of scientific phenomena against empirical evidence.

School Type and AI Competencies

School type was associated with substantial differences in AI awareness and AI-TPACK. Private-school teachers reported higher scores than state-school teachers, with the largest differences concentrated in AI-specific technological dimensions. These findings describe between-group differences in this sample; they do not establish that school type or institutional conditions produced those differences.

Prior research has linked technology integration with organizational conditions such as access to infrastructure and professional learning (Holmes & Miao, 2023; Saimon et al., 2024). Such factors may be relevant to the observed school-type differences, but infrastructure, institutional policy, frequency of AI use, and access to professional development were not measured in the present study. Accordingly, explanations based on greater familiarity or institutional support in private schools remain hypotheses for future research rather than conclusions from these data.

Differences in CK, PK, and PCK were relatively small, whereas several AI-specific technological dimensions showed much larger between-school differences. Future studies could examine access to AI tools, frequency and purpose of use, school-level support, and professional learning opportunities.

Private school teachers also obtained lower scores on the reverse-scored Risk Perception and Concerns subscale ($d = 1.36$), indicating greater reported concern about AI despite their higher AI-TPACK scores; this is in line with the positive relationship between concern and AI-TPACK noted above. The present study did not examine the mechanisms underlying this difference; therefore, explanations related to teachers' familiarity with AI, access to technological resources, or institutional support cannot be established from these data. Future studies could examine whether such contextual factors are associated with differences in teachers' perceptions of AI-related risks and concerns.

The school-type differences indicate a need for research that directly measures institutional resources and professional learning opportunities. In practice, equitable access to AI-related training and instructional resources can be considered alongside teacher-focused professional development, while the effectiveness of such measures should be evaluated through longitudinal or intervention studies.

Professional Experience and AI-Related Competencies

The relationship between professional experience and the two constructs was not linear. Early-career teachers (0–5 years) scored higher in several AI-related domains, teachers with 16–20 years scored lower in several dimensions of both scales, and the most experienced group (21 years or more) scored higher in several traditional content and pedagogical domains.

Experience thus appears to relate differently to traditional pedagogical knowledge and to AI-related competencies. Earlier studies have also found career-stage differences in teachers' AI-related competencies and learning experiences (Moorhouse et al., 2024; Yue et al., 2024). Because this study did not measure prior exposure to digital tools, frequency of AI use, or access to professional learning at different career stages, it cannot explain these differences; future studies could measure such factors to clarify why AI-related competencies differ by career stage.

Educational Attainment and AI Competencies

Educational attainment was associated with several dimensions of AI awareness and AI-TPACK, but the pattern was not uniform. Doctoral degree holders reported higher scores on several traditional content and pedagogical dimensions, whereas master's degree holders reported higher scores on some AI-specific technological dimensions.

The differences associated with educational attainment were less pronounced than those associated with AI-related training. However, the present study did not examine the specific learning experiences, curricular exposure, or professional development opportunities associated with participants' degree levels. The observed differences

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therefore should not be interpreted as effects of graduate education itself. Future research could examine which aspects of postgraduate education, if any, are associated with the development of AI-related competencies.

Gender Differences

Gender showed only limited differences in teachers' AI awareness and AI-TPACK. Female teachers scored higher on Ethical Awareness and Pedagogical Knowledge, but men and women did not differ on either total score. This pattern is consistent with previous studies reporting limited or dimension-specific gender differences in teachers' AI-related competencies (Ning et al., 2024; Yue et al., 2024). Because female teachers also reported greater AI-related concern, the gender differences appear to lie in the value-oriented components of awareness rather than in AI integration knowledge.

Limitations

Some limitations should be kept in mind. As a cross-sectional correlational study, it cannot support causal or temporal claims, and because a convenience sample was used, the results cannot be generalized to all science teachers. Both constructs were measured with self-report scales, so the scores show how teachers see themselves rather than how they actually teach. Several factors mentioned as possible explanations, including school infrastructure, how often teachers use AI, institutional support, and the content and quality of AI training, were not measured. Later research could add performance-based or observational data to self-reports and use longitudinal, multilevel, or intervention designs to test the explanations suggested here.

Conclusions and Implications

The findings showed that science teachers reported moderate levels of AI awareness and high levels of AI-TPACK. AI awareness was strongly and positively associated with AI-TPACK, indicating that teachers who reported greater awareness of AI also tended to report stronger perceived competencies for integrating AI into science teaching. These results indicate that AI awareness and AI-TPACK are closely related but conceptually distinct dimensions of teachers' readiness for AI-supported science teaching.

Differences by school type and AI-related training were larger than those by gender. Private-school teachers and teachers with AI training scored higher on both scales, while gender mattered for only a few dimensions. Professional experience and educational attainment were also related to several dimensions, though less consistently.

The findings suggest several areas for practice and further evaluation. Science teacher education, both before and during service, could cover AI literacy, ethical decisions about AI use, critical reading of AI-generated content, and applications specific to science. Because lower scores were observed among state-school teachers and teachers without AI-related training, equitable access to professional learning and AI-supported educational resources merits attention. In particular, in-service training for state school teachers and for teachers with 16–20 years of experience, who obtained the lowest scores, could concentrate on the AI-specific domains, such as AI-TK and AI-TCK, where the gaps were widest. However, the present study did not test whether these initiatives improve AI awareness, AI-TPACK, classroom practice, or student outcomes; these effects should be examined using longitudinal and intervention designs.

Finally, because AI awareness, including its value-oriented components, and AI integration knowledge were closely associated, teacher education programs may address them together, for example by combining practice with AI tools in science lessons with discussion of the ethical issues these tools raise.

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İsmail Satmaz PhD, Assistant Professor, Department of Educational Sciences, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye.
E-mail: ismailsatmaz@gmail.com
ORCID: https://orcid.org/0000-0003-2696-3019