

Natural sciences teachers' perceptions of AI-TPACK

ABSTRACT

This study aims to analyze Natural Sciences teachers' perceptions of the knowledge associated with Artificial Intelligence (AI) and its integration with the components of Technological Pedagogical Content Knowledge (AI-TPACK). This applied study adopted a quantitative, exploratory-descriptive approach and involved 27 Natural Sciences teachers. Data were collected using a self-report questionnaire comprising 14 statements rated on a four-point Likert scale, adapted from an instrument on AI-TPACK validated in the international literature. Data analysis involved descriptive statistics, a reliability test, normality tests, and the nonparametric Mann-Whitney U test to examine the effects of gender, age, and academic qualifications. The results reveal different levels of perceived AI-TPACK, with higher agreement scores for the dimensions related to content and inquiry-based practices and greater weaknesses in the pedagogical and integrative dimensions. Inferential analysis indicates that the level of academic qualification significantly influences teachers' perceptions of core dimensions of the model, whereas gender and age had no statistically significant effect. Although teachers recognize the potential of AI for Science Education, challenges remain concerning the development of pedagogical knowledge that can foster its critical and purposeful integration into teaching practices.

KEYWORDS: Artificial Intelligence; AI-TPACK; Natural Sciences.

Percepções de professores de ciências da natureza sobre o IA-TPACK

RESUMO

Este estudo visa analisar as percepções de professores de Ciências da Natureza sobre os conhecimentos relacionados à Inteligência Artificial (IA) articulados às bases do Conhecimento Tecnológico Pedagógico do Conteúdo (IA-TPACK). A pesquisa, de abordagem quantitativa, natureza aplicada e objetivo exploratório-descritivo, foi realizada com 27 professores de Ciências da Natureza. Os dados foram constituídos por meio de um questionário de autorrelato composto por 14 assertivas em escala Likert de quatro pontos, adaptado de instrumento validado na literatura internacional sobre IA-TPACK. As análises envolveram estatística descritiva, teste de confiabilidade, testes de normalidade e o teste não paramétrico de Mann-Whitney para verificar o efeito das variáveis gênero, idade e formação acadêmica. Os resultados evidenciam diferentes níveis de percepção sobre o IA-TPACK, com maiores índices de concordância nas bases relacionadas ao conteúdo e às práticas investigativas, e maiores fragilidades nas dimensões pedagógicas e integradoras. A análise inferencial indica que o nível de formação acadêmica influencia significativamente as percepções docentes em dimensões centrais do modelo, enquanto gênero e idade não apresentaram efeito estatístico. Embora os professores reconheçam o potencial da IA para o Ensino de Ciências, persistem desafios relacionados ao desenvolvimento de conhecimentos pedagógicos capazes de promover sua integração crítica e intencional às práticas docentes.

PALAVRAS-CHAVE: Inteligência Artificial; IA-TPACK; Ciências da Natureza.

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INTRODUCTION

Artificial Intelligence (AI) has assumed a central role in the contemporary transformation of educational systems, not merely as a supporting technology but as an element that reshapes epistemologies, pedagogical practices, and modes of scientific knowledge production. Recent reviews (Soto & Herrera, 2024; Siqueira et al., 2025) indicate that AI directly affects how scientific concepts are represented, investigated, and taught, requiring teachers to develop competencies that extend beyond technical and instrumental proficiency (Paidicán & Arredondo, 2024). In this context, understanding how Natural Sciences teachers perceive and conceptualize the integration of AI into teaching has become a central issue in educational research.

In the field of teacher education, the emergence of AI has challenged traditional models of professional knowledge, requiring frameworks capable of integrating technology, pedagogy, and content in a contextualized manner. The Technological Pedagogical Content Knowledge (TPACK) model, proposed by Mishra and Koehler (2006, 2009), has become one of the leading frameworks for understanding the pedagogical integration of digital technologies. However, recent studies suggest that the adaptive, generative, and algorithmic nature of AI limits the applicability of TPACK in its classical formulation, thus requiring its conceptual expansion (Karataş & Ataç, 2025).

In this study, AI is understood as a set of computational systems capable of performing tasks associated with human cognition, such as recognizing patterns, generating content, supporting decision-making, producing inferences, and personalizing teaching and learning processes (Celik, 2023; Ning et al., 2024; Soto & Herrera, 2024). In the context of Science Education, however, its meaning extends beyond the instrumental use of platforms or virtual assistants, as AI constitutes a resource capable of enhancing the modeling of phenomena, the visualization of abstract entities, the analysis of experimental data, the formulation of hypotheses, and the mediation of inquiry-based practices (Oliveira Figueiredo, 2025). From this perspective, AI does not replace teachers but expands their possibilities for planning, pedagogical intervention, and learning assessment, requiring critical, ethical, and epistemological knowledge for its integration into teaching (Selwyn, 2022; Soto & Herrera, 2024; Karataş & Ataç, 2025).

Recent studies have demonstrated this potential in different Science Education contexts, both through the use of generative systems to support chemistry teaching (Junior, 2025) and through reflections on the development of AI-TPACK-related teacher knowledge (Bedin, 2026), as well as the advocacy of critical and contextualized pedagogical practices in which digital technologies are connected to educational intentionality and citizenship education (Vasselai & Morais, 2022).

In light of these transformations, there has been an increase in studies proposing extensions of TPACK, giving rise to the AI-TPACK construct, which explicitly incorporates the knowledge required for the pedagogical integration of AI. International research has sought to examine the structure, components, and internal relationships of this expanded model, demonstrating that AI-TPACK encompasses specific cognitive, ethical, pedagogical, and disciplinary dimensions (Ning et al., 2024; Xu et al., 2025; An et al., 2025). These studies emphasize that

the integration of AI into teaching cannot be understood as a mere continuation of previous digital technologies.

At the empirical level, recent studies have explored the relationship between teachers' competencies, attitudes toward AI, and levels of AI-TPACK knowledge. Runge et al. (2025) demonstrate that preservice teachers' acceptance of AI is strongly associated with the quality of the education they receive and the development of integrated knowledge. Similarly, Hava and Babayiğit (2025) and Setiyawan et al. (2025) show that higher levels of AI-TPACK are associated with digital proficiency, teacher self-efficacy, and the ability to make informed pedagogical decisions in AI-mediated contexts.

In the context of Natural Sciences education, these discussions are particularly relevant because this field involves high levels of conceptual abstraction and the extensive use of models, simulations, and inquiry-based practices. Recent studies (Oliveira Figueiredo, 2025) indicate that AI has the potential to transform how scientific phenomena are explored, represented, and understood. However, it may also reinforce technicist approaches if it is not mediated by pedagogical intentionality and an epistemological understanding of the content. Therefore, analyzing teachers' perceptions is essential to understanding the limitations and possibilities of AI in Science Education.

Despite advances in international research, studies that jointly investigate Brazilian Natural Sciences teachers' perceptions and conceptions of AI knowledge connected to the components of TPACK remain scarce, particularly regarding the integration of technology, pedagogy, and science in initial teacher education (Bedin & Morais, 2024). Recent scientometric reviews (Siqueira et al., 2025) identify gaps concerning teachers' understanding of the ethical, pedagogical, and disciplinary integration of AI, especially in educational settings marked by structural inequalities. Furthermore, studies indicate that familiarity with digital technologies does not necessarily ensure the development of integrated and critical knowledge (Aldemir et al., 2025; Eyal, 2025), demonstrating that the development of teacher knowledge requires reflective and self-regulated processes (Bedin, 2025b).

In this regard, understanding how Natural Sciences teachers perceive and conceptualize knowledge about AI in relation to the different dimensions that constitute the TPACK model represents a relevant issue from both theoretical and teacher-education perspectives. Teachers' perceptions directly influence pedagogical decisions, planning approaches, and ways of adopting technologies, thereby mediating the relationship between educational innovation policies and actual classroom practices (Ning et al., 2024; Karataş & Ataç, 2025).

Against this background, this study aims to analyze Natural Sciences teachers' perceptions of knowledge related to Artificial Intelligence (AI) and its connections with the components of Technological Pedagogical Content Knowledge (AI-TPACK). Accordingly, it seeks to understand how teachers assess their ability to integrate AI with scientific content, pedagogical decision-making, and technology use, as well as the intersections among these dimensions. In doing so, the study contributes to advancing the debate on AI-TPACK and provides a foundation for developing critical, ethical, and epistemologically informed teacher-education initiatives in Science Education.

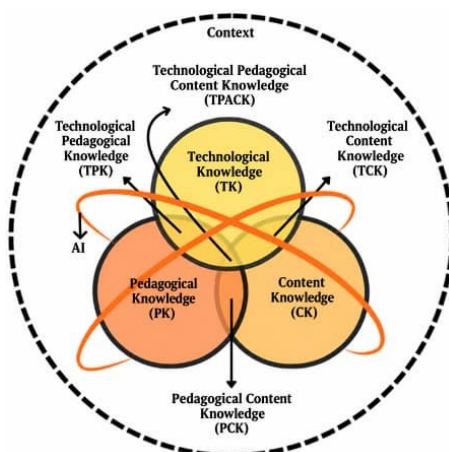
THEORETICAL FOUNDATIONS

AI-TPACK MODEL

The AI-TPACK model emerges as a critical extension of the TPACK framework by recognizing that AI cannot be understood merely as an additional technological resource but rather as a sociotechnical, epistemological, and pedagogical phenomenon that reshapes teachers' professional knowledge. Recent studies indicate that AI affects not only the use of educational tools but also how scientific knowledge is produced, interpreted, and taught (Karataş & Ataç, 2025; Ning et al., 2024; Siqueira et al., 2025). From this perspective, this article argues that, within AI-TPACK, AI permeates all the knowledge domains of the model, redefining the teacher's role in relation to content, pedagogical practices, and learning processes in educational contexts increasingly mediated by intelligent systems, as shown in Figure 1.

Figure 1

The TPACK model permeated by AI, giving rise to AI-TPACK



Source: The authors, 2026.

Within Content Knowledge (CK), the presence of AI is manifested in the re-configuration of scientific knowledge, investigative methods, and ways of learning concepts. The use of algorithms, simulations, predictive modeling, and generative systems changes how scientific phenomena are understood and represented, requiring teachers to develop a broader epistemological understanding of the content they teach (Park et al., 2023; Ning et al., 2024). Thus, even when technologies are not used directly in the classroom, AI influences CK by redefining what counts as valid knowledge, scientific evidence, and disciplinary explanation, thereby justifying its structural inclusion within this domain of the model (Voogt et al., 2013).

Similarly, Pedagogical Knowledge (PK) is also permeated by the logic of AI. AI affects conceptions of teaching, learning, assessment, and classroom management by introducing new possibilities for personalization, monitoring student progress, and supporting pedagogical decision-making (Runge et al., 2025; Hava & Babayiğit, 2025). Even when it is not operationalized through digital tools, AI

influences PK by modifying pedagogical expectations, criteria for monitoring learning, and conceptions of feedback and teacher intervention, reinforcing the notion that its impact extends beyond the strictly technological dimension (Soto & Herrera, 2024).

Within Pedagogical Content Knowledge (PCK), AI assumes a central role by supporting conceptual mediation, the anticipation of learning difficulties, and the selection of representations best suited to specific content. Research indicates that AI-based systems help teachers understand error patterns, conceptual gaps, and learning trajectories, directly influencing how content is pedagogically reorganized (An et al., 2025; Setiawan et al., 2025). In this way, AI not only complements PCK but also transforms it, requiring teachers to develop a greater capacity to connect scientific explanation, pedagogical decision-making, and the critical interpretation of educational data generated by intelligent systems.

Technological Knowledge (TK), in turn, concerns the critical and functional understanding of AI systems, tools, platforms, and architectures. Moving beyond an instrumental perspective, AI-TK encompasses both operational familiarity with AI-based technologies and an understanding of their underlying principles, limitations, algorithmic biases, ethical implications, and educational impacts (Celik, 2023; Ning et al., 2024). AI-TK provides an essential foundation for the pedagogical integration of AI because it enables teachers to critically assess when, how, and why particular intelligent systems should—or should not—be used (Runge et al., 2025; Hava & Babayiğit, 2025). AI-TK is not limited to technical proficiency but is connected to AI literacy, understood as the ability to question intelligent technologies and make responsible decisions regarding them, thereby avoiding uncritical or technocentric uses in teaching (Soto & Herrera, 2024).

The traditional intersections of the model—Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK)—remain essential but are now understood as levels of progressive integration. TCK demonstrates how AI transforms scientific investigative practices, visualizations, and simulations; TPK explains how pedagogy is reorganized by algorithmic logic and educational data analysis; and TPACK represents the most complex level, at which content, pedagogy, and AI are intentionally, critically, and epistemologically integrated (Xu et al., 2025; Eyal, 2025). This level requires a high degree of professional maturity and teacher reflection, as indicated by studies on preservice and continuing teacher education (Aldemir et al., 2025; Oliveira Figueiredo, 2025).

Therefore, arguing that AI permeates the entire TPACK model means recognizing that it is not merely a technology to be integrated but a structuring element of contemporary teacher knowledge, capable of redefining what is taught, how it is taught, and how learning is understood. This interpretation broadens the theoretical scope of AI-TPACK and supports a teacher-education approach that moves beyond technicism by emphasizing the centrality of pedagogical intentionality, critical thinking, and epistemological responsibility in teacher education. Accordingly, AI-TPACK has become established as a model for understanding and guiding the critical integration of AI into education. Although it preserves the assumptions of the model originally proposed by Mishra and Koehler (2006, 2009), this interpretation recognizes that AI introduces changes profound enough

to justify a transformative understanding of AI-TPACK, particularly in the context of Science Education.

In this regard, the conception of AI-TPACK adopted in this study aligns with the transformative perspective on TPACK proposed by Angeli and Valanides (2013), according to which teachers' professional knowledge does not result from the simple combination of technological, pedagogical, and content knowledge. Instead, it constitutes qualitatively new knowledge produced through the dynamic interaction among these dimensions. From this perspective, AI is not an additional resource to be incorporated into teaching but an element capable of reshaping the nature of pedagogical decisions, representations of scientific knowledge, and forms of learning mediation. Thus, AI-TPACK is understood as extending beyond an integrative view centered on the incorporation of technology and assuming a transformative character by recognizing that AI redefines the very foundations of teacher knowledge, requiring new epistemological, ethical, and pedagogical competencies for teaching Science.

RELATED WORK

The concept of AI-TPACK emerges as a natural extension of the classical debates surrounding TPACK, reaffirming the need to integrate content, pedagogical, and technological knowledge in response to the specific characteristics of AI. Foundational scholars in the field of TPACK, such as Mishra and Koehler (2009), provide the starting point for these connections. Subsequent literature has emphasized that the adaptive and generative properties of AI require additional dimensions—for example, algorithmic literacy, ethical assessment, and the ability to evaluate biases—that extend beyond traditional Technological Knowledge (Angeli & Valanides, 2013; Celik, 2023). Soto and Herrera (2024) corroborate the need for this conceptual reconfiguration, arguing that AI-TPACK is not merely another form of technology but a construct with its own epistemological and pedagogical implications.

From a methodological perspective, a significant line of research has focused on measuring and validating the components of AI-TPACK through the development of specific scales and instruments. Studies such as those by An et al. (2025) and Karataş and Ataç (2025) have advanced the field by proposing validated instruments and employing structural equation modeling to map relationships among AI-TPACK components. Concurrently, validation studies conducted in various contexts demonstrate that AI-TPACK dimensions can be operationalized, although considerable variation exists among studies regarding items, factors, and psychometric robustness (Setiyawan et al., 2025; Hava & Babayiğit, 2025). These efforts have contributed to establishing AI-TPACK as a measurable variable that can be compared across studies, while also raising challenges concerning cultural equivalence and contextualization.

Another emerging line of research relates attitudes, self-efficacy, and acceptance of AI to levels of AI-TPACK. Studies adapting technology acceptance models indicate that favorable attitudes toward AI and teacher self-efficacy serve as crucial mediators in the development of AI-TPACK (Xu et al., 2025; Runge et al., 2025). In these studies, specific training in AI, practical experiences, and AI literacy modules tend to increase both confidence and AI-TPACK competence. How-

ever, this relationship is not linear and depends on factors such as disciplinary content and the quality of teacher education (Aldemir et al., 2025; Ning et al., 2024).

In the Brazilian context, Bedin (2026) analyzed chemistry teachers' perceptions of AI-TPACK and found that teachers recognize the potential of Artificial Intelligence to support teaching but continue to exhibit weaknesses in integrating pedagogical, technological, and content knowledge. These findings reinforce the understanding that consolidating AI-TPACK depends on teacher-education processes that extend beyond instrumental proficiency in technologies and promote their critical integration into pedagogical practices. Within this context, the literature suggests that changes in attitudes and professional development are important but insufficient preconditions for meaningful pedagogical integration.

Teacher-education interventions focused on AI-TPACK constitute another growing area of research. Experimental and quasi-experimental studies have examined intensive courses, AI literacy modules, and instructional design strategies for both preservice and practicing teachers. Initial evidence indicates that short modules—for example, lasting one to two weeks—promote instrumental gains and greater awareness (Aldemir et al., 2025), whereas longer, inquiry-oriented programs tend to foster pedagogical integration and the ability to provide didactic justification (Eyal, 2025). Nevertheless, a recurring tension remains: many programs prioritize technical skills at the expense of ethical and epistemological problematization, thereby limiting their transfer to disciplinary teaching practices (Selwyn, 2022).

At the disciplinary level, studies of AI-TPACK in specific subject areas have multiplied, particularly in the natural and exact sciences. Research on the integration of AI into science lessons highlights the potential of intelligent simulations, assisted modeling, and data analysis to enrich inquiry-based practices. However, it also draws attention to the challenges of aligning scientific representations with algorithms (Park et al., 2023). Research in chemistry education, for example, indicates that incorporating AI requires teachers to master both conceptual content and the methodological implications of these tools (Bedin et al., 2025; Bedin & das Graças Cleophas, 2024), particularly among preservice teachers (Abreu & Bedin, 2025).

Similarly, Junior (2025) analyzed the use of ChatGPT in chemistry education, demonstrating that generative Artificial Intelligence tools can foster the exploration of scientific concepts when employed with pedagogical intentionality and teacher mediation. The study also shows that the educational potential of these technologies depends less on their features than on the pedagogical decisions guiding their use, an aspect consistent with the assumptions of AI-TPACK. Thus, AI-TPACK varies across disciplinary contexts: certain components, such as AI-TCK, may be more highly developed, whereas its integrative core—AI-TPACK—remains weak.

Bibliometric mappings and systematic reviews provide a broader overview of current trends. Studies such as Siqueira et al. (2025), as well as thematic reviews (Ning et al., 2024; Soto & Herrera, 2024; Paidicán & Arredondo, 2024), demonstrate exponential growth in research on AI in education and the early emergence of the term AI-TPACK across different scientific communities. These reviews also

identify methodological gaps, including the predominance of cross-sectional studies, a scarcity of longitudinal research, and limited geographical or contextual diversity in many samples, reinforcing the need for more robust and comparative investigations.

Finally, critical and prospective literature problematizes the risks and future scenarios associated with the widespread incorporation of AI into teaching. Critical scholars warn against technosolutionism, the normalization of AI tools, and the need for public policies that integrate teacher education, equity, and regulation (Selwyn, 2022). At the same time, contemporary proposals seek to redefine teacher readiness for the AI era by emphasizing ethical competencies, algorithmic literacy, and professional autonomy (Sharma & Elaish, 2025; Oliveira, 2025). Overall, research on AI-TPACK is promising and diverse: conceptual development, instrumentation, and teacher-education interventions have advanced, but empirical gaps, validation challenges, and a critical research agenda continue to call for more comprehensive and context-sensitive educational approaches.

METHODOLOGY

This study was approved by the Research Ethics Committee of the Federal University of Paraná under CAAE No. 84735324.1.0000.0214. It adopted a quantitative approach, an exploratory-descriptive design, and an applied nature, as it seeks to analyze teachers' perceptions within a real and specific professional development context. It does not aim for broad statistical generalization but instead focuses on understanding emerging trends and patterns (Gil, 2019). Exploratory-descriptive studies are appropriate when the phenomenon under investigation is still undergoing theoretical and empirical consolidation, as is the case with the AI-TPACK construct in the field of teacher education (Ning et al., 2024).

The study included 27 Natural Sciences teachers who participated voluntarily, constituting a nonprobability convenience sample composed of individuals directly connected to the field under investigation (Stratton, 2021). The choice of this sampling method was justified by the specific characteristics of the target population and the feasibility of accessing the participants. This method is widely employed in exploratory educational research and makes it possible to obtain informed perceptions from individuals who experience, to varying degrees, processes involving the integration of technology and AI into teaching.

Data were collected using a structured self-report questionnaire (Table 1) comprising 14 statements (A–N) organized on a four-point Likert scale ranging from strongly disagree to strongly agree. No neutral response option was provided, thus encouraging respondents to express a position. According to Colton and Covert (2007), scales of this type are appropriate for measuring attitudes, perceptions, and self-reported assessments in social and educational studies. The statements were based on the instrument developed and validated by Setiyawan et al. (2025) to measure teachers' AI-TPACK. Minor linguistic and contextual adaptations were made to align the instrument with the Brazilian context and the specific target population of the study, following the methodological recommendations of DeVellis and Thorpe (2021).

Table 1

Questionnaire used for data collection

Statements		
AI-CK	A	I understand how fundamental AI concepts affect, expand, or challenge scientific knowledge in my teaching field.
	B	I clearly understand how advances in AI influence the scientific concepts of my subject area.
AI-PK	C	I can use AI to accommodate different learning paces and styles, ensuring that each student receives appropriate pedagogical support.
	D	I can continuously monitor students' progress using AI tools and adjust my pedagogical interventions when necessary.
AI-TK	E	I can independently explore different AI tools and assess which ones are best suited to my context.
	F	I feel confident in my ability to solve basic technical problems when using AI-based educational tools.
AI-PCK	G	I can develop teaching strategies in which AI directly supports the construction of concepts specific to my subject area.
	H	I can use AI tools to provide more precise conceptual feedback aligned with my learning objectives.
AI-TPK	I	I can provide a pedagogical justification for selecting an AI tool based on learning objectives and students' needs.
	J	I can adapt an AI technology to integrate it into different teaching methods while maintaining consistency with the pedagogical approach.
AI-TCK	K	I recognize how AI technologies influence, expand, or transform inquiry-based practices in my field of knowledge.
	L	I can select AI tools that support the visualization, analysis, or simulation of concepts specific to my subject area.
AI-TPACK	M	I can plan lessons in which content, pedagogy, and AI tools interact in an integrated manner to promote meaningful learning.
	N	I can integrate teaching methods, AI tools, and disciplinary knowledge to address complex teaching and learning problems.

Source: Research data, 2026.

The questionnaire, which included two statements for each domain of the AI-TPACK model, was made available digitally through Google Forms. This strategy ensured accessibility, rapid data collection, and reliable data storage, in addition to facilitating data export for statistical analysis (Marconi & Lakatos, 2004). Following data collection, the data were organized in an electronic spreadsheet and analyzed using version 20 of the Statistical Package for the Social Sciences (SPSS).

Before the inferential analyses were conducted, the data underwent rigorous statistical screening procedures. First, the instrument's internal reliability was assessed using Cronbach's alpha coefficient, which is widely employed to evaluate the internal consistency of psychometric scales (DeVellis & Thorpe, 2021). The resulting value ($\alpha = 0.937$) indicates an excellent level of reliability, suggesting a high degree of homogeneity among the statements and strong internal consistency within the instrument. According to the literature, alpha values greater than 0.90 indicate high precision and psychometric robustness, particularly in educational studies investigating complex and multidimensional constructs such as teachers' professional knowledge (Hair et al., 2019).

Normality tests were subsequently performed to examine the distribution of the data and support the selection of the statistical procedures to be employed. Given the nonnormal distribution of the data and the small sample size, nonparametric statistical procedures were selected. Descriptive statistical analyses were conducted for the 14 statements, including measures of central tendency and dispersion. The Mann-Whitney U test was also employed to investigate possible differences in teachers' perceptions according to gender, age group, and level of academic qualification. The Mann-Whitney U test is appropriate for comparisons between two independent groups when the assumptions of parametric statistics are not met (McKight & Najab, 2010). Statistical significance was established at $p < 0.05$.

The results were interpreted using an interpretive-inductive approach (Marconi & Lakatos, 2004), connecting the statistical findings with the theoretical framework of the field—particularly studies on TPACK and AI-TPACK—and with the participants' profiles. This approach made it possible to move beyond a numerical description of the data and develop a critical and contextualized interpretation of teachers' perceptions, as advocated by Gil (2019), even in quantitative studies.

RESULTS

The analysis of the participants' profiles revealed a heterogeneous sample in terms of gender, age group, and academic qualifications, making it possible to understand perceptions arising from different educational backgrounds. The study included 27 Natural Sciences teachers: 14 men (51.9%), 12 women (44.4%), and one participant who self-identified as another gender (3.7%). Regarding age, teachers older than 27 years predominated, accounting for 77.8% of the sample ($n = 21$), whereas 22.2% ($n = 6$) were 27 years old or younger. Academic qualifications were also diverse and included teachers with an undergraduate degree (29.6%, $n = 8$) and postgraduate qualifications: specialization certificates (7.4%, $n = 2$), master's degrees (33.3%, $n = 9$), and doctoral degrees (29.6%, $n = 8$). These data reflect different levels of academic qualification and stages of professional development. All participants worked in the field of Natural Sciences, irrespective of their specific teaching degree, as the research instrument did not distinguish among the different qualifications within this field.

After characterizing the participants' profiles, which were operationalized as the study variables of gender, age group, and level of academic qualification, descriptive statistical analyses of the statements were conducted to identify central tendencies, dispersion, and general patterns in teachers' perceptions of the AI-TPACK domains (Table 2). Subsequently, based on the results of the Shapiro-Wilk and Kolmogorov-Smirnov normality tests, which indicated heterogeneity and a violation of the assumption of normality, the nonparametric Mann-Whitney U test was performed using the Wilcoxon statistic and Z score (Table 3). This test, which is appropriate for comparisons between independent groups, was used to examine the effects of gender, age, and academic qualifications on the perceptions expressed in the statements.

Table 2
Descriptive Statistics

Statistics	A	B	C	D	E	F	G
Median	3.00	3.00	3.00	2.00	3.00	3.00	4.00
Standard deviation	0.688	0.594	0.877	1.122	1.055	0.892	1.064
Minimum	2	2	2	1	1	1	1
Maximum	4	4	4	4	4	4	4
Percentile 25	3.00	3.00	3.00	2.00	2.00	2.00	2.00
Percentile 50	3.00	3.00	3.00	2.00	3.00	3.00	4.00
Percentile 75	4.00	4.00	4.00	4.00	4.00	3.00	4.00

Statistics	H	I	J	K	L	M	N
Median	3.00	3.00	3.00	4.00	3.00	3.00	3.00
Standard deviation	0.934	0.892	0.898	0.643	0.921	0.940	0.980
Minimum	2	2	1	2	2	2	1
Maximum	4	4	4	4	4	4	4
Percentile 25	3.00	3.00	2.00	3.00	3.00	3.00	2.00
Percentile 50	3.00	3.00	3.00	4.00	3.00	3.00	3.00
Percentile 75	4.00	4.00	4.00	4.00	4.00	4.00	4.00

Source: Research data, 2026.

Table 3
Mann-Whitney U Test for the Variables of Gender, Age, and Academic Qualification

Gender Variable							
	A	B	C	D	E	F	G
U	68.000	78.500	59.000	84.000	78.000	75.500	85.500
W	188.000	198.500	179.000	204.000	156.000	153.500	205.500
Z	-1.185	-0.646	-1.631	-0.304	-0.621	-0.768	-0.239
p	0.236	0.519	0.103	0.761	0.534	0.442	0.811
	H	I	J	K	L	M	N
U	71.500	60.500	65.000	85.000	89.500	87.500	73.500
W	149.500	180.500	185.000	205.000	167.500	207.500	151.500
Z	-0.963	-1.551	-1.300	-0.281	-0.026	-0.131	-0.846
p	0.336	0.121	0.194	0.779	0.979	0.895	0.398

Age Variable							
	A	B	C	D	E	F	G
U	57.000	76.500	67.500	85.000	85.500	85.500	81.000
W	135.000	154.500	145.500	163.000	163.500	205.500	159.000
Z	-1.778	-0.758	-1.184	-0.253	-0.233	-0.238	-0.477
p	0.075	0.449	0.236	0.800	0.816	0.812	0.633
	H	I	J	K	L	M	N
U	68.000	80.000	81.500	75.500	81.000	61.000	87.000
W	146.000	158.000	159.500	153.500	159.000	139.000	207.000
Z	-1.145	-0.526	-0.442	-0.814	-0.473	-1.525	-0.154
p	0.252	0.599	0.659	0.416	0.636	0.127	0.878

Academic Qualification Variable							
	A	B	C	D	E	F	G
U	38.000	44.500	54.000	72.500	75.000	83.500	38.000
W	93.000	99.500	109.000	127.500	130.000	236.500	93.000

Z	-2.605	-2.340	-1.679	-0.651	-0.533	-0.082	-2.565
p	0.009	0.019	0.093	0.515	0.594	0.935	0.010
	H	I	J	K	L	M	N
U	40.000	36.000	40.500	47.000	63.000	55.500	71.000
W	95.000	91.000	95.500	102.000	118.000	110.500	126.000
Z	-2.410	-2.652	-2.381	-2.195	-1.191	-1.596	-0.738
p	0.016	0.008	0.017	0.028	0.234	0.110	0.460

Note: U = Mann-Whitney test statistic; W = Wilcoxon statistic (sum of ranks); Z = standardized statistic for the normal approximation; p = asymptotic significance (two-tailed test). **Source:** Research data, 2026.

Overall, the results of the Mann-Whitney U test revealed no statistically significant differences according to gender or age, suggesting relative homogeneity in teachers' perceptions across the respective groups. However, the same test indicated that the level of academic qualification had a statistically significant influence on participants' perceptions regarding a specific set of statements in the instrument. Significant effects were found for statements A (U = 38.000; p = 0.009), B (U = 44.500; p = 0.019), G (U = 38.000; p = 0.010), H (U = 40.000; p = 0.016), I (U = 36.000; p = 0.008), J (U = 40.500; p = 0.017), and K (U = 47.000; p = 0.028), indicating that perceptions associated with these AI-TPACK dimensions varied according to the participants' level of academic qualification.

For these statements, the Mann-Whitney U test for independent samples was subsequently applied through customized pairwise comparisons to further examine the effects identified. This analytical step made it possible to assess the asymptotic significance (two-tailed test) of differences among the levels of academic qualification and compare the mean ranks assigned to each group. This procedure provides a more detailed understanding of how different educational backgrounds influence teachers' perceptions of specific AI-TPACK dimensions.

DISCUSSION

TEACHERS' PERCEPTIONS OF THE AI-TPACK DOMAINS

The descriptive statistical analysis of the 14 statements, organized according to the AI-TPACK domains, reveals different patterns in the appropriation of AI among Natural Sciences teachers. The results indicate specific advances in certain dimensions of teacher knowledge, alongside disparities in teacher education and varying levels of response dispersion in the domains requiring greater integration among content, pedagogy, and technology. This body of evidence points to an empirical gradient in the appropriation of AI within the model, without presupposing linear progression across its domains.

Statements A and B, related to AI-CK, had a median of 3 and a 75th percentile of 4, indicating that at least 75% of the participants ranged from partial to complete agreement regarding their understanding of AI's impact on scientific concepts in their field. The low standard deviations (A = 0.688; B = 0.594) reveal homogeneous perceptions, suggesting that teachers recognize the conceptual influence of AI on scientific knowledge with relative consistency. This result is consistent with Chen et al. (2022) and Holmes et al. (2019), who indicate that AI has primarily been incorporated as a means of epistemologically expanding disci-

plinary knowledge, even before its systematic pedagogical integration. Within the AI-TPACK framework, this finding indicates that AI-CK tends to become consolidated earlier than the other domains.

In contrast, statements C and D, associated with AI-PK, reveal greater dispersion and weakness. Statement C had a median of 3, a 25th percentile of 3, and a high standard deviation (0.877), whereas statement D had a median of 2, a 25th percentile of 2, and an even higher standard deviation (1.122). These results indicate that a significant proportion of teachers do not perceive themselves as capable of using AI to personalize learning or continuously monitor student progress. These findings align with Celik et al. (2022), who argue that the pedagogical use of AI is one of the most complex dimensions of teacher education because it requires didactic intentionality, pedagogical knowledge, and an understanding of algorithmic affordances. Within the AI-TPACK model, the data suggest that AI-PK constitutes one of the primary teacher-education bottlenecks.

Statements E and F, related to AI-TK, both had medians of 3, with 75th percentiles of 4 for E and 3 for F, as well as moderate standard deviations ($E = 1.055$; $F = 0.892$). These results indicate that teachers perceive themselves as relatively autonomous in exploring AI tools and solving basic technical problems, although this perception is not entirely homogeneous. This pattern is consistent with studies showing that instrumental mastery of technology tends to precede its pedagogical and conceptual integration (Hava & Babayiğit, 2025). However, as Selwyn (2022) and Mishra et al. (2023) caution, technical proficiency in isolation may reinforce technicist approaches if it is not connected to the other AI-TPACK domains, an issue frequently identified in studies based on teachers' self-reported technological competence (Nascimento et al., 2025).

Statements G and H, associated with AI-PCK, reveal an intermediate pattern. Statement G had a median of 4, with both the 50th and 75th percentiles also at 4, indicating that half of the teachers reported a high level of ability to integrate AI into the construction of concepts specific to their subject areas. However, the standard deviation of 1.064 suggests considerable heterogeneity. Statement H had a median of 3, a 75th percentile of 4, and a standard deviation of 0.934, indicating that although the potential of AI to support conceptual development and feedback is recognized, this integration has not yet been fully consolidated. Studies by Karataş and Ataç (2025) and Park et al. (2023) indicate that AI-PCK strongly depends on epistemological knowledge of the subject area, which helps explain the variability observed among teachers, particularly the results concerning AI-PK.

Statements I and J, related to AI-TPK, both had medians of 3, 75th percentiles of 4, and standard deviations close to 0.9, indicating moderate perceptions of teachers' ability to pedagogically justify the use of AI and adapt it to different teaching methods. These results demonstrate that teachers recognize the importance of pedagogical coherence but continue to experience difficulties in applying it consistently. This finding is widely discussed by Angeli and Valanides (2013) and Runge et al. (2025), who maintain that AI-TPK represents a critical transition between technical proficiency and the reflective pedagogical integration of AI.

Within AI-TCK, statements K and L produced relatively positive results. Statement K stood out, with a median of 4, 50th and 75th percentiles also at 4, and a low standard deviation (0.643), indicating strong consensus regarding recognition of AI's impact on inquiry-based practices in the scientific field. Statement L, in turn, had a median of 3, a 75th percentile of 4, and a standard deviation of 0.921. These findings corroborate Chen et al. (2022), who indicate that AI has been readily adopted in inquiry-based activities, simulations, and scientific visualizations, particularly in the Natural Sciences.

Finally, statements M and N, which represent the integrative core of AI-TPACK, both had medians of 3, 75th percentiles of 4, and high standard deviations ($M = 0.940$; $N = 0.980$). These results indicate that although some teachers perceive themselves as capable of planning integrated lessons and addressing complex problems using AI, their perceptions vary considerably. This pattern is consistent with Mishra and Koehler (2006, 2009) and Celik (2023), who argue that AI-TPACK constitutes higher-order knowledge that depends on sustained educational experiences, critical reflection, and the epistemological integration of technology, pedagogy, and content.

These findings reinforce the understanding that consolidating the integrative core of AI-TPACK is associated with teacher-education processes that extend beyond technical and instrumental proficiency, requiring systematic reflection, self-regulation, and metacognitive awareness from teachers (Bedin, 2025a, 2025b). When technological integration is understood as a metacognitive practice, teachers reflect not only on the use of technology but also on the pedagogical, epistemological, and ethical reasons guiding their instructional decisions, thereby increasing the complexity of this professional knowledge (Bedin, 2025a). In this regard, the high variability observed in statements M and N indicates that these processes have not yet been fully structured in initial teacher education. This finding exposes the limitations of teacher-education programs in consistently fostering the integrated articulation of content, pedagogy, and AI and confirms the difficulty of consolidating the model's integrative core at this stage of teacher education (Abreu & Bedin, 2025).

Overall, the descriptive statistics reveal a progressive gradient in the appropriation of AI-TPACK. The domains most closely associated with scientific content and recognition of AI's impact—AI-CK and AI-TCK—show higher levels of agreement and lower response dispersion. In contrast, the domains requiring pedagogical mediation and the simultaneous integration of content, pedagogy, and AI—AI-PK, AI-TPK, and especially AI-TPACK—show intermediate levels of agreement and greater variability, revealing weaknesses in teacher education within these dimensions.

What is particularly noteworthy, however, is the pattern observed for AI-TK, which exhibited intermediate levels of agreement, with a substantial proportion of participants concentrated between partial disagreement and partial agreement. This result indicates that although teachers recognize the impact of AI on scientific content and inquiry-based practices in their field, they do not perceive themselves as fully autonomous or confident in exploring and selecting AI tools or solving technical problems related to their use. This finding reveals that AI-TK has not yet been consolidated as AI literacy but remains at an incipient stage characterized by operational uncertainty and dependence on ready-made solu-

tions. This weakness in the technological domain helps explain the difficulties observed in the model's more integrative dimensions, as a lack of technical autonomy limits the transfer of AI to intentional and contextualized pedagogical applications.

In other words, the observed pattern suggests that teachers recognize the epistemological and technological relevance of AI but experience difficulties in translating it into intentional and integrated pedagogical strategies for Natural Sciences education. These findings align with the international literature in indicating that the appropriation of AI-TPACK develops progressively and is conditioned by teachers' educational experiences, requiring opportunities for systematic reflection and deeper epistemological understanding for its consolidation (Ning et al., 2024; Xu et al., 2025; Sharma & Elaish, 2025). Thus, in addition to characterizing levels of perceived knowledge, the descriptive statistics reveal the main areas of tension in teacher education concerning the critical and pedagogical use of AI. In this context, inferential analysis using the Mann-Whitney U test provides a deeper understanding of these results by examining how these perceptions differ according to the educational backgrounds of the participating teachers.

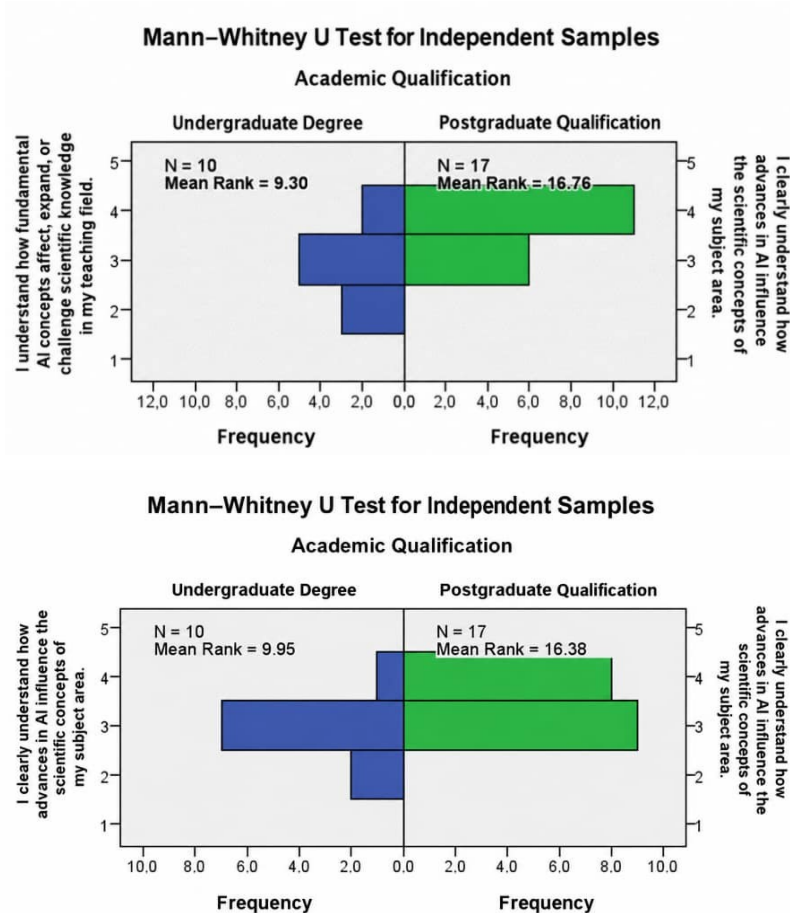
INFLUENCE OF DEMOGRAPHIC VARIABLES ON TEACHERS' PERCEPTIONS

The Mann-Whitney U test for independent samples, considering academic qualification as a variable (undergraduate and postgraduate), revealed that the level of academic qualification had a statistically significant influence on teachers' perceptions regarding statements A and B (AI-CK), G and H (AI-PCK), and I and J (AI-TPK). The results consistently indicate that teachers with postgraduate qualifications obtained higher mean ranks for these statements than those whose highest qualification was an undergraduate degree, suggesting a more consolidated perception of the connections among AI, scientific content, and pedagogical decision-making. This pattern reinforces the understanding that AI-TPACK knowledge does not develop immediately but is strongly associated with longer, more reflective, and inquiry-oriented educational trajectories, as argued by Mishra and Koehler (2009), Celik (2023), and Karataş and Ataç (2025).

For statements A and B (AI-CK), which address teachers' understanding of AI's impact on scientific concepts, the significant difference between undergraduate and postgraduate qualifications indicates that teachers with more advanced academic education tend to have greater epistemological clarity regarding how AI expands, challenges, or problematizes scientific knowledge (Figure 2). This finding is consistent with studies indicating that postgraduate education fosters engagement with research practices, critical interpretations of science, and discussions concerning the sociotechnical implications of technology, all of which are essential to consolidating AI-CK (Chen et al., 2022; Holmes et al., 2019; Ning et al., 2024). Within the Brazilian context, this result may also be interpreted in light of educational disparities between undergraduate and postgraduate education, as epistemological reflection on science and technology tends to be addressed more systematically at advanced levels of academic education.

Figure 2

Mann-Whitney U test for independent samples for statements A and B, respectively

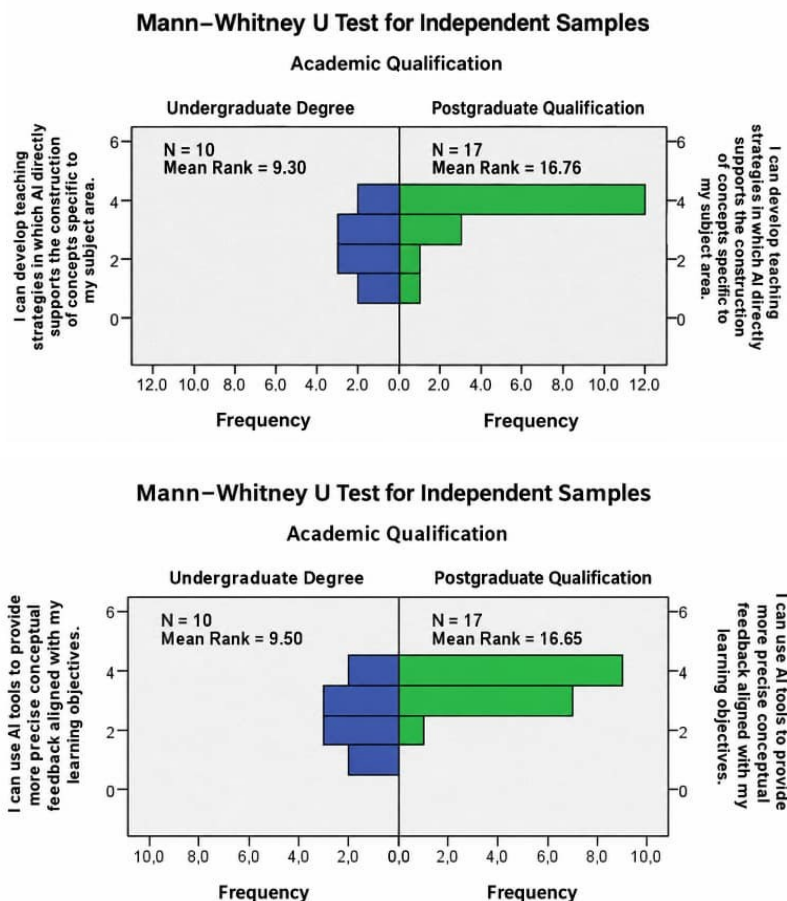


Source: Research data, 2026.

The differences observed for statements G and H (AI-PCK), which concern the ability to use AI to directly support the construction of disciplinary concepts and provide high-quality conceptual feedback, reinforce the understanding that the pedagogical integration of AI with scientific content constitutes a particularly complex dimension of AI-TPACK. Participants at the postgraduate level reported higher perceived knowledge in this domain (Figure 3). This finding aligns with Karataş and Ataç (2025) and Park et al. (2023), who demonstrate that AI-PCK depends on a thorough understanding of both the content and the pedagogical possibilities afforded by technology. Initial teacher education, in turn, tends to prioritize conceptual knowledge of the subject in a fragmented manner, which may explain the more moderate perceptions among undergraduate participants.

Figure 3

Mann-Whitney U test for independent samples for statements G and H, respectively

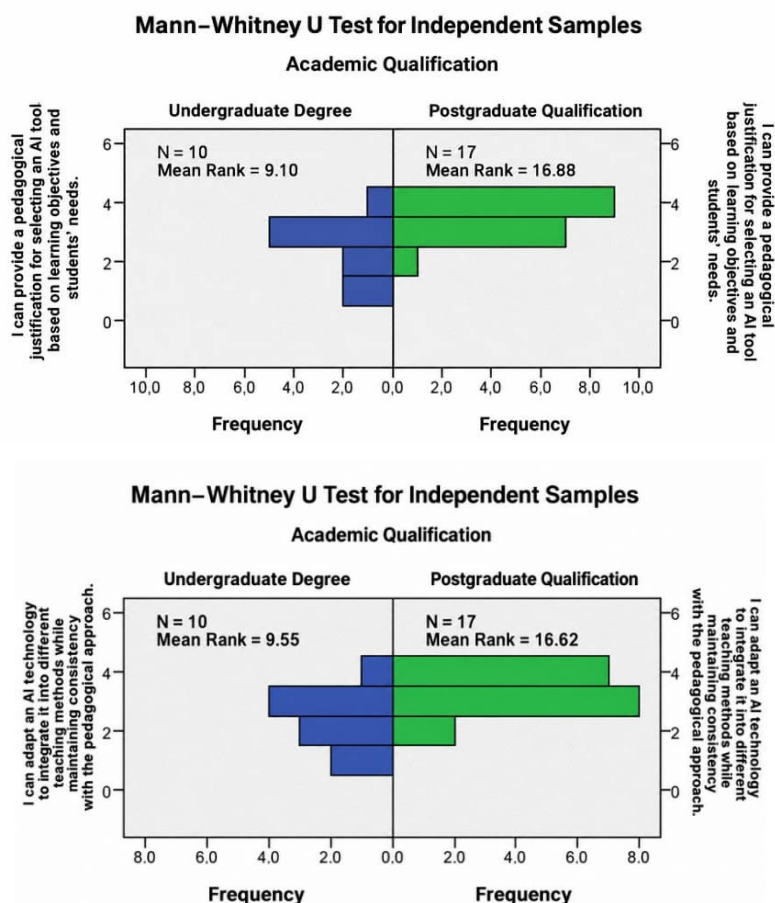


Source: Research data, 2026.

Similarly, statements I and J (AI-TPK), which are associated with the pedagogical justification for using AI and adapting the technology to different teaching methods, showed statistically significant differences according to academic qualification. This result indicates that teachers with postgraduate qualifications perceive themselves as more capable of making informed and coherent pedagogical decisions regarding the use of AI (Figure 4), a central aspect of AI-TPACK. Angeli and Valanides (2013) and Runge et al. (2025) emphasize that pedagogical justification is an indicator of advanced technological integration that is rarely consolidated during the initial stages of teacher education. Similarly, Celik (2023) argues that the ethical and pedagogical integration of AI emerges primarily in educational contexts that foster critical reflection, self-regulation, and analysis of the educational implications of technology.

Figure 4

Mann-Whitney U test for independent samples for statements I and J, respectively



Source: Research data, 2026.

The statistically significant differences identified for statements A, B, G, H, I, J and K reinforce the understanding that academic qualification is a determining factor in the development of the more complex dimensions of AI-TPACK. This result is consistent with research examining preservice teachers in recent technological contexts (Bedin & Morais, 2024). These findings do not indicate resistance to AI among preservice teachers; rather, they reveal structural limitations in undergraduate teacher-education programs regarding the systematic promotion of the epistemological, pedagogical, and technological integration of AI. From a critical perspective, the data signal an urgent need for policies and teacher-education initiatives that introduce inquiry-based, reflective, and ethically oriented experiences during initial teacher education, thereby fostering the progressive development of AI-TPACK in Natural Sciences education.

When the different results are considered together, the statistically significant differences identified between participants at the undergraduate and postgraduate levels do not emerge in isolation; instead, they are directly related to the patterns of dispersion, medians, and quartiles observed in the descriptive statistics. In other words, descriptive statistics indicate the level of agreement, whereas inferential testing reveals who expresses this agreement more consistently.

For statements A and B (AI-CK), for example, although the descriptive statistics indicated high medians and low standard deviations, suggesting general consensus regarding the impact of AI on scientific concepts, the inferential test revealed that this consensus differed qualitatively according to the level of academic qualification. Participants at the postgraduate level tended to obtain higher mean ranks, indicating a deeper and more epistemologically informed understanding of the role of AI in producing and problematizing scientific knowledge, as discussed by Chen et al. (2022), Mishra and Koehler (2009), and Karataş and Ataç (2025).

A similar pattern was observed for statements G and H (AI-PCK) and I and J (AI-TPK), which exhibited intermediate medians, high 75th percentiles, and higher standard deviations in the descriptive analysis, revealing greater heterogeneity in participants' perceptions. This scenario is clarified by the Mann-Whitney test, demonstrating that the dispersion may be largely associated with differences in teachers' educational trajectories. Undergraduate participants were concentrated at the partial-agreement levels, whereas postgraduate participants were predominantly situated at the upper levels of the scale, reflecting a greater perceived ability to intentionally integrate AI, pedagogy, and content.

Ultimately, the results make it possible to interpret AI-TPACK beyond a strictly integrative perspective on teacher knowledge. Although the classical TPACK model has frequently been understood as the integration of technological, pedagogical, and content knowledge (Mishra & Koehler, 2006; Graham, 2011), the findings of this study suggest that AI does not merely represent a new technological resource to be incorporated into pedagogical practices. Its presence modifies how scientific knowledge is produced, reorganizes teaching and learning processes, and expands the possibilities for instructional mediation, thus affecting every domain of the model.

In this regard, this interpretation aligns with the transformative perspective proposed by Angeli and Valanides (2013), according to which the interaction among technology, pedagogy, and content results in the constitution of new professional knowledge that is qualitatively distinct from the mere sum of its components. From this perspective, AI-TPACK can be understood as a reconfiguration of teacher knowledge in response to the specific characteristics of AI, requiring teachers to develop competencies that extend beyond instrumental proficiency in technology and encompass critical judgment, epistemological understanding, ethical reflection, and pedagogical decision-making. Thus, AI no longer occupies a peripheral position in the model but assumes a structuring role in the constitution of teachers' professional knowledge.

CONCLUSION

This study aimed to analyze Natural Sciences teachers' perceptions of AI knowledge when connected to the domains of TPACK. The results indicate that although teachers broadly recognize the epistemological relevance and potential of AI for Science Education—particularly regarding the expansion of inquiry-based practices, the visualization of phenomena, and the problematization of scientific concepts—this recognition does not consistently translate into integrated AI-TPACK knowledge. Significant disparities are therefore evident among

the different dimensions of teacher knowledge, revealing teacher-education tensions that permeate the pedagogical appropriation of AI.

Overall, the analyses show that teachers' perceptions tend to be more consolidated in the dimensions associated with content and the technological impact of AI, whereas more pronounced weaknesses emerge in the pedagogical and integrative domains of the model. These weaknesses become particularly evident in dimensions requiring intentional instructional planning, personalized learning, and pedagogical justification for the use of AI. The inferential analysis reinforces this interpretation by indicating that the level of academic qualification significantly influences teachers' perceptions, suggesting that longer and more advanced educational trajectories foster a more interconnected and integrated understanding of AI-TPACK.

The main contribution of this research lies in empirically demonstrating that the integration of AI into the education of Natural Sciences teachers cannot be understood merely as an issue of access or isolated technical proficiency. The findings indicate that the central challenge lies in constructing integrated professional knowledge capable of supporting pedagogical, epistemological, and ethical decisions concerning the use of AI. In this regard, the study reinforces the need to reconsider curricula and policies for initial and continuing teacher education, shifting the focus from instrumental approaches toward intentional, critical, and integrative educational processes that recognize AI as a structuring, rather than merely ancillary, element of teacher knowledge.

The limitations of the study include the size and nature of the sample, as well as the use of self-reported data, which do not allow direct inferences regarding the pedagogical practices actually implemented in the classroom. Furthermore, the cross-sectional design prevents the examination of how AI-TPACK knowledge evolves over time. Future research should employ mixed-methods or qualitative approaches incorporating classroom observations, analyses of lesson plans, and in-depth interviews, as well as longitudinal studies capable of examining how AI-TPACK develops throughout initial teacher education and teachers' professional careers. Such studies may contribute to a deeper understanding of how AI can effectively become established as a meaningful pedagogical element in Natural Sciences education.

Based on the weaknesses identified, the following priority actions are recommended to strengthen AI-TPACK among Natural Sciences teachers: (i) *the systematic inclusion of AI in initial teacher education*, connected to specific disciplinary content and not limited to instrumental approaches; (ii) *the development of inquiry-based educational experiences* involving the planning, implementation, and critical reflection on the use of AI in authentic teaching situations; (iii) *an emphasis on the pedagogical and ethical dimensions of AI*, fostering informed and context-sensitive instructional decision-making; (iv) *the integration of research and teacher education*, enabling teachers to engage with inquiry-based practices and epistemological debates concerning science and technology; and (v) *continuing teacher-education programs* that progressively and reflectively integrate technology, pedagogy, and content.

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NOTES

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REFERÊNCIAS

- Abreu, M. E. S. A., & Bedin, E. (2025). A integração das bases do tpack no ensino de química: compreensões de professores em formação inicial. *Revista Dynamis*, 31, e12540-e12540. <https://doi.org/10.7867/1982-48662025e12540>
- Aldemir, T., Bicer, A., Kilinc, S., Moon, J., & Kwok, M. (2025). Exploring emergent AI-TPACK competencies in a two-week AI literacy module for preservice teachers. *Teaching and Teacher Education*, 168, 105231. <https://doi.org/10.1016/j.tate.2025.105231>
- An, X., Bai, J., Li, Y., Zhou, Y., Chai, C. S., & Hong, J. C. (2025). Development of an Artificial Intelligence Technology Pedagogical Content Knowledge (AI-TPACK) Scale for Human and AI Concurrently as Teachers: X. An et al. *The Asia-Pacific Education Researcher*, 1-11. <https://doi.org/10.1007/s40299-025-01045-2>
- Angeli, C., & Valanides, N. (2013). Technology mapping: An approach for developing technological pedagogical content knowledge. *Journal of Educational Computing Research*, 48(2), 199-221. <https://doi.org/10.2190/EC.48.2.e>
- Bedin, E. (2026). Autodeclaração docente e inteligência artificial: percepções de professores de química sobre o domínio do IA-CTPC. *Revista de Ensino de Ciências e Matemática*, 17(2), 1-26. <https://doi.org/10.26843/rencima.v17n2a05>
- Bedin, E. (2025a). Da resolução de caso à autorreflexão: contribuições da metacognição para a integração do TPACK. *Amazônia: Revista de Educação em Ciências e Matemáticas*, 21(47), 5-18. <http://dx.doi.org/10.18542/amazrecm.v21i47.19426>
- Bedin, E. (2025b). Metacognição e CTPC: uma nova perspectiva para a Formação Docente Reflexiva e Autorregulada. *Paradigma*, e2025013-e2025013. <https://doi.org/10.37618/PARADIGMA.1011-2251.2025.e2025013.id1626>
- Bedin, E., & das Graças Cleophas, M. (2024). Um retrato sobre o conhecimento tecnológico pedagógico do conteúdo de professores de química durante a

- pandemia a partir do olhar discente. *ETD: Educação Temática Digital*, (26), 64. <https://doi.org/10.20396/etd.v26i00.8670173>
- Bedin, E., & Morais, C. S. L. (2024). Percepções de professores de química em formação inicial quanto à articulação tecnologia-pedagogia-ciência em suas práticas na pandemia. *Educar em Revista*, 40. <https://doi.org/10.1590/1984-0411.87730>
- Bedin, E., de Siqueira, L. E., de Lima, V. F., & de Oliveira Viviani, A. C. C. (2025). Mapeando o domínio conceitual TPACK de professores em formação inicial. *Singular. Sociais e Humanidades*, 1(7), 95-108. <https://doi.org/10.33911/singularsh.v1i7.212>
- Celik, I. (2023). Towards Intelligent-TPACK: An empirical study on teachers' professional knowledge to ethically integrate artificial intelligence (AI)-based tools into education. *Computers in human behavior*, 138, 107468. <https://doi.org/10.1016/j.chb.2022.107468>
- Celik, I., Dindar, M., Muukkonen, H., & Järvelä, S. (2022). The promises and challenges of artificial intelligence for teachers: A systematic review of research. *TechTrends*, 66(4), 616-630. <https://doi.org/10.1007/s11528-022-00715-y>
- Chen, X., Zou, D., Xie, H., Cheng, G., & Liu, C. (2022). Two decades of artificial intelligence in education. *Educational Technology & Society*, 25(1), 28-47. <https://www.jstor.org/stable/48647028>
- Colton, D., & Covert, R. W. (2007). *Designing and constructing instruments for social research and evaluation*. John Wiley & Sons.
- DeVellis, R. F., & Thorpe, C. T. (2021). *Scale development: Theory and applications*. Sage publications.
- Eyal, L. (2025). Developing and validating an AI-TPACK Assessment Framework: Enhancing Teacher Educators' Professional Practice Through Authentic Artifacts. *Education Sciences*, 15(11), 1452. <https://doi.org/10.3390/educsci15111452>
- Gil, A. C. (2019). *Métodos e Técnicas de Pesquisa Social*. 7. São Paulo: Atlas.
- Hava, K., & Babayiğit, Ö. (2025). Exploring the relationship between teachers' competencies in AI-TPACK and digital proficiency. *Education and information technologies*, 30(3), 3491-3508. <https://doi.org/10.1007/s10639-024-12939-x>
- Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education promises and implications for teaching and learning*. Center for Curriculum Redesign.
- Junior, I. L. C. (2025). Análise do ChatGPT como ferramenta no ensino de química: explorando o tema matéria e energia. *ACTIO: Docência em Ciências*, 10(2), 1-23. <https://doi.org/10.3895/actio.v10n2.19066>

- Karataş, F., & Ataç, B. A. (2025). When TPACK meets artificial intelligence: Analyzing TPACK and AI-TPACK components through structural equation modelling. *Education and Information Technologies*, 30(7), 8979-9004. <https://doi.org/10.1007/s10639-024-13164-2>
- Marconi, M. D., & Lakatos, E. M. (2004). *Metodologia científica*. 4. São Paulo: Atlas.
- McKight, P. E., & Najab, J. (2010). Kruskal-wallis test. The corsini encyclopedia of psychology, 1-1. <https://doi.org/10.1002/9780470479216.corpsy0491>
- Mishra, P., & Koehler, M. (2009). Too cool for school? No way! Using the TPACK framework: You can have your hot tools and teach with them, too. *Learning & Leading with Technology*, 36(7), 14-18.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers college record*, 108(6), 1017-1054. <https://doi.org/10.1111/j.1467-9620.2006.00684.>
- Mishra, P., Warr, M., & Islam, R. (2023). TPACK in the age of ChatGPT and Generative AI. *Journal of Digital Learning in Teacher Education*, 39(4), 235-251. <https://doi.org/10.1080/21532974.2023.2247480>
- Nascimento, E. M., Bedin, E., & Gasparini, F. S. (2025). Autodeclaração tecnológica de pibidianos de Química frente às bases do TPACK. *Educitec-Revista de Estudos e Pesquisas sobre Ensino Tecnológico*, 11(jan./dez.), e260625-e260625. <https://doi.org/10.31417/educitec.v11.2606>
- Ning, Y., Zhang, C., Xu, B., Zhou, Y., & Wijaya, T. T. (2024). Teachers' AI-TPACK: Exploring the relationship between knowledge elements. *Sustainability*, 16(3), 978. <https://doi.org/10.3390/su16030978>
- Oliveira Figueiredo, L., Lopes, A. M. Z., Validorio, V. C., & Mussio, S. C. (2023). Desafios e impactos do uso da Inteligência Artificial na educação. *Educação Online*, 18(44), e18234408-e18234408. <https://doi.org/10.36556/eol.v18i44.1506>
- Paidicán, S. M., & Arredondo, H. P. (2024). La inteligencia artificial en contextos del conocimiento técnico pedagógico del contenido (TPACK): Una revisión bibliográfica. *Panorama*, 18(35).
- Park, J.; Teo, T.W.; Teo, A.; Chang, J.; Huang, J.S.; Koo, S. Integrating artificial intelligence into science lessons: Teachers' experiences and views. *Int. J. STEM Educ.* 2023, 10, 61. <https://doi.org/10.1186/s40594-023-00454-3>
- Runge, I., Hebibi, F., & Lazarides, R. (2025). Acceptance of pre-service teachers towards artificial intelligence (AI): The role of AI-related teacher training courses and AI-TPACK within the technology acceptance model. *Education Sciences*, 15(2), 167. <https://doi.org/10.3390/educsci15020167>

- Selwyn, N. (2022). The future of AI and education: Some cautionary notes. *European Journal of Education*, 57(4), 620-631.
<https://doi.org/10.1111/ejed.12532>
- Setiyawan, A., Soeharto, S., Wijaya, T. T., Korenova, L., & Lavicza, Z. (2025). Measuring Teachers' Competencies for AI Integration: Development and Validation of the AI-TPACK in Vocational Education. *Computers and Education Open*, 100319. <https://doi.org/10.1016/j.caeo.2025.100319>
- Sharma, S., & Elaish, M. (2025). Extending AI-TPACK: Reframing teacher readiness for the generative-AI era. *Journal of Educational Thought / Revue de la Pensée Educative*, 58(2), 111–134.
- Siqueira, L. E., Bedin, E., & Grando, J. W. (2025). Inteligência artificial na educação: Revisão cienciométrica e proposta de articulação pelo modelo TPACK. *Educação, Formação & Tecnologias*, 13(1), 59–85.
<https://doi.org/10.5281/zenodo.16741209>
- Soto, M. P., & Herrera, P. A. (2024). Artificial intelligence in technical pedagogical content knowledge (TPACK) contexts: A literature review. *Panorama*, 18(35).
<https://doi.org/10.15765/pkjpww56>
- Stratton, S. J. (2021). *Population research*: convenience sampling strategies. *Pre-hospital and disaster Medicine*, 36(4), 373-374.
<https://doi.org/10.1017/S1049023X21000649>
- Vasselai, M. P., & de Moraes, J. L. (2022). The three pedagogical moments and the portfolio methodology: analysis of a pedagogical practice aimed at achieving a critical environmental education. *ACTIO: Docência em Ciências*, 7(3), 1-19.
<https://doi.org/10.3895/actio.v7n3.15246>
- Voogt, J.; Fisser, P.; Pareja Roblin, N.; Tondeur, J.; van Braak, J. Technological pedagogical content knowledge—a review of the literature. *J. Comput. Assist. Learn.* 2013, 29, 109–121. <https://doi.org/10.1111/j.1365-2729.2012.00487.x>
- Xu, G., Yu, A., Gao, A., & Trainin, G. (2025). Developing an AI-TPACK framework: Exploring the mediating role of AI attitudes in pre-service TCSL teachers' self-efficacy and AI-TPACK. *Education and Information Technologies*, 1–25.
<https://doi.org/10.1007/s10639-025-13630-5>

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