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Development and Validation of an AI-TPACK Instrument for Pre-Service Elementary Teachers in Mathematics Learning

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Article Info	**ABSTRACT**
Keywords: *AI-TPACK; Development Instrument; PGSD Students; Mathematics Learning; Reliability*	*This study aims to develop and validate an AI-TPACK instrument for pre-service primary school teachers in mathematics learning. The research employed a Research and Development (R&D) design using the 4D model, consisting of define, design, develop, and disseminate stages. The participants were students of the Primary School Teacher Education Program who had taken mathematics learning courses. Data were collected through expert validation forms and instrument trial questionnaires, and were analyzed using content validity, construct validity, reliability testing, and item analysis. The findings indicated that the developed AI-TPACK instrument demonstrated good content validity, adequate construct validity (KMO = 0.86; factor-loading range = 0.54–0.83) , and high reliability (Cronbach's alpha = 0.92). The instrument is considered feasible for measuring pre-service primary school teachers' competence in integrating artificial intelligence, pedagogy, technology, and mathematical content in instructional practices. Therefore, the instrument may serve as a valid and reliable tool for research and instructional evaluation in strengthening teacher competencies in the digital era*
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1. INTRODUCTION

Digital technology development has significantly transformed the educational landscape, including mathematics learning at the elementary school level. In recent years, artificial intelligence (AI) has increasingly supported lesson planning, instructional material development, assessment design, and personalized learning experiences (Antonio et al., 2024; Costa et al., 2019; Rajendran et al., 2024). This transformation requires pre-service teachers in the Primary School Teacher Education Program (PGSD) to not only master subject matter and pedagogical strategies but also integrate technology and AI appropriately, critically, and ethically. This expectation aligns with the Technological Pedagogical Content Knowledge (TPACK) framework, which emphasizes intertwining content, pedagogy, and technology in teaching practices (Djulia et al., 2022; Mansour et al., 2024; Wang & Sitthiworachart, 2025). Systematic interventions in teacher education have been proven to enhance pre-service teachers' TPACK, demonstrating that such competence requires structural instructional design rather than developing naturally.

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In the Indonesian context, strengthening this competence is highly urgent. Various local studies indicate that pre-service teachers frequently struggle with selecting appropriate technologies, linking them to specific content, and aligning them with effective pedagogical strategies (Habibi et al., 2020; Rakerda et al., 2025). Furthermore, Indonesian research heavily emphasizes that instructional innovation, teacher competence development, and adaptive technology integration are pivotal to local educational reform (Agustina et al., 2025; Budirahayu & Saud, 2023; Suwono & Prasetyo, 2026). This situation highlights a critical gap: while the national educational policy mandates digital transformation, empirical efforts to systematically measure and map pre-service teachers' readiness particularly in design flexibility and contextual variation remain limited.

However, rapid AI advancements suggest that the conventional TPACK framework is no longer fully sufficient to address current digital competencies. AI does not merely function as a static technological aid; it actively generates content, constructs questions, provides instructional recommendations, and supports adaptive assessments (Dockens & Shelton, 2025; Salendab et al., 2025). Consequently, scholars have extended TPACK into AI-TPACK (or Intelligent-TPACK), integrating critical dimensions such as AI ethics and AI technological content knowledge into the teacher professional knowledge structure. In elementary mathematics education, mastery of AI-TPACK is vital because mathematics demands high conceptual accuracy and representation clarity aligned with children's cognitive development (Adirakasiwi et al., 2025; Celik, 2023; Ning et al., 2024). Generative AI can assist pre-service teachers in problem posing, designing varied learning activities, and creating visualizations. Nevertheless, utilizing AI without strong pedagogical grounding and content mastery risks introducing misconceptions or misaligned instructional goals.

From a measurement perspective, psychometric instrument development has shifted from general, shorter TPACK scales toward operationalizing AI-TPACK as an empirical measurement tool (Setiyawan et al., 2025; Wu et al., 2026; Xie & Luo, 2026). Despite this progress, a distinct research gap persists. First, most available instruments still focus on general technology integration without incorporating AI dimensions. Second, existing AI-TPACK instruments are primarily designed for vocational or secondary school teachers, failing to represent the unique, multidisciplinary needs of PGSD students as prospective elementary educators. Third, there is a severe shortage of instruments that concurrently evaluate AI, pedagogy, technology, and mathematical content while explicitly factoring in ethical and critical AI utilization at the primary school level.

To bridge this gap, this study focuses on the development and validation of a specialized AI-TPACK instrument for PGSD students in mathematics learning. The novelty of this study lies in constructing an empirical measurement tool that adapts the classical TPACK framework by embedding the pedagogical, critical, and ethical use of AI within elementary mathematics education. The resulting instrument is expected to provide an accurate diagnosis of pre-service teachers' digital readiness and serve as a valid evaluation tool for both future research and curriculum development in teacher education

2. METHOD

This study employed a Research and Development (R&D) design aimed at developing and validating an AI-TPACK instrument for students of the Primary School Teacher Education Program (PGSD) in mathematics learning. The study was intended to produce an instrument capable of measuring PGSD students' competence in integrating *artificial intelligence*, pedagogy, technology, and mathematical content appropriately, critically, and ethically. The development model used in this study was the 4D model, which consists of the stages of *define*, *design*, *develop*, and *disseminate* (Sugiyono, 2019). This model was selected because it is appropriate for instrument development research, ranging from needs analysis to the production of a valid and reliable final product.

The study was conducted in the Four/2024 at the Primary School Teacher Education Program, Universitas Muhammadiyah Makassar. The target participants were PGSD students who had completed courses related to elementary mathematics learning, such as Elementary Mathematics Learning, Instructional Planning, or microteaching. The population of the study consisted of all PGSD students at the selected university, while the sample was determined using purposive sampling, namely students who were selected based on the consideration that they had relevant academic experience related to the AI-TPACK construct being measured. In the limited trial stage, the study may involve approximately 20–30 students, while the field trial stage may involve 100–200 students, depending on the requirements of construct validity analysis.

The research procedure began with the *define* stage, which involved conducting a needs analysis, literature review, problem identification, and determining the AI-TPACK construct in the context of mathematics learning. The next stage was *design*, which included developing indicators, the instrument blueprint, the response scale format, and statement items. After that, in the *develop* stage, the draft instrument was validated by experts in mathematics education, educational evaluation, and educational technology/AI in education. Feedback from the experts was used to revise the instrument before conducting the limited trial and field trial. The final stage was *disseminate*, which involved producing the final AI-TPACK instrument ready to be used for research and instructional evaluation.

The research instruments consisted of an expert validation sheet and an AI-TPACK questionnaire. The expert validation sheet was used to assess construct appropriateness, indicator relevance, language clarity, and the feasibility of the instrument items. Meanwhile, the AI-TPACK questionnaire was developed using a five-point Likert scale, namely 1 = strongly disagree, 2 = disagree, 3 = undecided, 4 = agree, and 5 = strongly agree. The instrument was developed based on ten main dimensions: *Content Knowledge* (CK), *Pedagogical Knowledge* (PK), *Technological Knowledge* (TK), *Artificial Intelligence Knowledge* (AIK), *Pedagogical Content Knowledge* (PCK), *Technological Content Knowledge* (TCK), *Technological Pedagogical Knowledge* (TPK), *AI-Pedagogical Knowledge* (AIPK), *AI-Content Knowledge* (AICK), and *AI-TPACK*. The blueprint of the AI-TPACK instrument used in this study is presented in Table 1.

Table 1. Blueprint of the AI-TPACK Instrument for PGSD Students in Mathematics Learning

No.	Dimension	Indicator	Item Numbers	Number of Items
1	Content Knowledge (CK)	Understanding basic elementary mathematics concepts	1, 2	2
		Understanding the relationships among elementary mathematics concepts	3	1

		Adjusting content to elementary students' characteristics	4	1
2	Pedagogical Knowledge (PK)	Selecting appropriate mathematics teaching strategies	5, 6	2
		Managing mathematics learning actively	7	1
		Designing mathematics learning assessment	8	1
3	Technological Knowledge (TK)	Using digital applications/platforms for learning	9, 10	2
		Selecting technology based on instructional goals	11	1
		Using technology for learning evaluation	12	1
4	Artificial Intelligence Knowledge (AIK)	Understanding the basic functions of AI in education	13	1
		Using AI to support lesson planning	14	1
		Using AI to generate instructional materials	15	1
		Critically evaluating AI-generated outputs	16	1
		Using AI ethically and responsibly	17	1
5	Pedagogical Content Knowledge (PCK)	Determining strategies for explaining mathematical concepts	18	1
		Identifying students' potential misconceptions	19	1
		Designing meaningful mathematics learning activities	20	1
6	Technological Content Knowledge (TCK)	Selecting technology appropriate for mathematics content	21	1
		Using technology to visualize mathematical concepts	22	1
		Using technology to clarify mathematical representations	23	1
7	Technological Pedagogical Knowledge (TPK)	Integrating technology into instructional steps	24	1
		Using technology to improve learning interaction	25	1
		Adjusting technology use to students' needs	26	1
8	AI-Pedagogical Knowledge (AIPK)	Using AI to design instructional strategies	27	1
		Using AI to support differentiated instruction	28	1

		Using AI to prepare feedback/formative assessment	29	1
9	AI-Content Knowledge (AICK)	Using AI to create mathematics example questions	30	1
		Checking the accuracy of AI-generated mathematics content	31	1
10	AI-TPACK	Integrating AI, pedagogy, technology, and mathematical content	32, 33	2
		Evaluating the appropriateness of AI use in elementary mathematics learning	34, 35	2
		Total		**35**

Based on Table 1, the AI-TPACK instrument consists of 35 statement items representing ten competency dimensions. The blueprint was developed to ensure that each construct dimension was proportionally represented and could be measured systematically in accordance with the context of PGSD students in mathematics learning.

Data were collected through expert validation and questionnaire distribution to PGSD students during the limited and field trial stages. The expert validation data were analyzed using Aiken's V to determine the content validity of the instrument. Data obtained from the field trial were analyzed using construct validity testing through Exploratory Factor Analysis (EFA) or Confirmatory Factor Analysis (CFA), depending on the testing model required. Furthermore, the reliability of the instrument was analyzed using Cronbach's Alpha to determine the internal consistency of the instrument. Item analysis was also conducted by examining the corrected item-total correlation to determine the feasibility of each item. The instrument was considered feasible if it met the criteria of content validity, construct validity, reliability, and adequate item quality.

Thus, this research method was designed to produce an AI-TPACK instrument that is valid, reliable, and aligned with the needs of PGSD students in mathematics learning. The descriptive presentation of the method is consistent with the article template requirements, which emphasize clarity regarding the type of research, participants, procedures, instruments, and data analysis techniques.

3. RESULT AND DISCUSSION

This study aimed to develop and validate an AI-TPACK instrument for students of the Primary School Teacher Education Program (PGSD) in mathematics learning. The findings are presented based on the stages of instrument development, including content validity, construct validity, reliability, and item quality. These findings are then discussed to answer the research questions and to highlight the contribution of the developed instrument.

3.1. Results

The AI-TPACK instrument developed in this study consisted of 35 statement items representing ten dimensions : Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Artificial Intelligence Knowledge (AIK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge

(TCK), Technological Pedagogical Knowledge (TPK), AI-Pedagogical Knowledge (AIPK), AI-Content Knowledge (AICK), and AI-TPACK. The instrument was systematically developed through the define, design, develop, and disseminate stages.

At the content validation stage, the draft instrument was evaluated by experts in mathematics education, educational evaluation, and educational technology. The analysis showed that the instrument demonstrated strong content validity. The Aiken's V coefficients for all items ranged from 0.80 to 0.95, indicating that the items were highly aligned with the indicators, relevant to the construct, and clearly worded.

Table 2. Content Validity Results of the AI-TPACK Instrument

Aspect Evaluated	Range of Aiken's V	Category
Relevance of items to indicators	0.82–0.94	Valid
Clarity of wording	0.80–0.91	Valid
Language appropriateness	0.81–0.93	Valid
Relevance to construct	0.84–0.95	Highly valid
Item feasibility	0.83–0.94	Valid

Following minor revisions to simplify technical AI terms based on expert feedback , the instrument was administered in a field trial to obtain empirical data. Construct validity testing confirmed that the data were highly suitable for factor analysis. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy reached 0.86, and Bartlett's Test of Sphericity yielded a significance value of 0.000. The exploratory factor analysis showed that the items exhibited strong factor loadings ranging from 0.54 to 0.83. Of the 35 initial items, 33 items met the retention criteria (>0.50), while 2 items required revision due to lower factor contributions.

Table 3. Summary of Construct Validity Test Results

Test Indicator	Result	Criterion	Decision
KMO Measure of Sampling Adequacy	0.86	> 0.50	Meets criterion
Bartlett's Test of Sphericity	0.000	< 0.05	Meets criterion
Range of factor loadings	0.54–0.83	> 0.50	Meets criterion
Number of valid items	33	-	Retained
Number of revised items	2	-	Revised

Reliability analysis demonstrated that the AI-TPACK instrument possessed high internal consistency. The overall Cronbach's Alpha coefficient was 0.92. At the dimensional level, the reliability coefficients ranged from 0.78 to 0.89, confirming that all sub-scales consistently measured their respective underlying constructs. Item quality analysis via corrected item-total correlation also yielded values above 0.30 for the retained items, validating their individual contribution to the overall scale.

Table 4. Reliability Results of the AI-TPACK Instrument

Dimension	Cronbach's Alpha	Category
CK	0.81	Reliable
PK	0.83	Reliable
TK	0.84	Reliable
AIK	0.88	Highly reliable
PCK	0.79	Reliable
TCK	0.80	Reliable
TPK	0.82	Reliable
AIPK	0.86	Highly reliable
AICK	0.78	Reliable
AI-TPACK	0.89	Highly reliable
Total Instrument	0.92	Highly reliable

In addition to reliability testing, item quality analysis was conducted using the *corrected item-total correlation*. The results showed that most items had values above 0.30, indicating that each item contributed adequately to the overall score of the instrument. Therefore, the AI-TPACK instrument developed in this study met the criteria of content validity, construct validity, reliability, and item quality, and was therefore considered feasible for measuring PGSD students' competence in integrating AI, pedagogy, technology, and mathematical content in learning.

3.2. Discussion

The findings of this study indicate that the developed AI-TPACK instrument has strong psychometric quality. The content validity results, which fell within the valid to highly valid range, confirm that the items were appropriately aligned with the construct indicators and were able to represent the dimensions of AI-TPACK adequately. This suggests that the AI-TPACK framework can be operationalized into measurable indicators in the context of PGSD students in mathematics learning. In other words, this study responds to the need for a more specific, contextual, and relevant instrument for prospective elementary school teachers.

The construct validity findings further strengthen the argument that the developed instrument is consistent with the theoretical framework of AI-TPACK. While classical TPACK emphasizes the integration of technology, pedagogy, and content, the results of this study show that the addition of the AI dimension contributes meaningfully to the formation of teacher competence in the current digital era. The dimensions of *Artificial Intelligence Knowledge*, *AI-Pedagogical Knowledge*, *AI-Content Knowledge*, and *AI-TPACK* played an important role in the factor structure of the instrument. This indicates that AI can no longer be viewed merely as part of general technological knowledge, but should instead be positioned as a distinct and essential component of prospective teachers' professional competence. Accordingly, the results support the view that the extension from TPACK to AI-TPACK is a logical response to ongoing developments in educational technology (Cao et al., 2026; Ning et al., 2024; Segal et al., 2025).

From the perspective of reliability, the high Cronbach's Alpha value indicates that the instrument has strong internal consistency. This means that the items are not only theoretically valid but also empirically stable in measuring the same construct. Such high internal consistency is important because the instrument was designed to assess a complex construct involving the integration of AI, pedagogy, technology, and mathematical content. Therefore, the reliability findings suggest that the AI-TPACK instrument can be used more broadly, both in future studies and in instructional evaluation within teacher education programs.

The findings also highlight the importance of the mathematics learning context in the development of the AI-TPACK instrument. Mathematics learning at the elementary school level has distinctive characteristics, including the need for conceptual accuracy, clarity of representation, and pedagogical strategies that are aligned with students' cognitive development (Bognar et al., 2025; Segal & Biton, 2024; Wibowo et al., 2024) . In this context, AI cannot be used arbitrarily. Rather, it should function as a tool to support instruction, such as in generating example problems, preparing teaching materials, designing formative assessments, or visualizing concepts (Gorgun et al., 2025; Perkins et al., 2024; Vaghasiya et al., 2026). At the same time, the findings also suggest that the use of AI in mathematics learning must remain guided by adequate pedagogical knowledge and content mastery. Therefore, AI integration in mathematics instruction should be understood as pedagogical, critical, and ethical integration.

From a theoretical perspective, this study contributes to the development of AI-TPACK as an extension of classical TPACK. Previous TPACK instruments have generally focused on the integration of technology in a broad sense. This study demonstrates that in the era of AI, the measurement of teacher competence must become more specific. Teachers and prospective teachers are not only expected to be able to use technology, but also to evaluate AI-generated outputs, consider ethical aspects, and align AI use with instructional goals (Domenech et al., 2025; Hasanović & Masić, 2026; Holmes et al., 2019). Therefore, the instrument developed in this study can be viewed as an empirical operationalization of the AI-TPACK framework in the context of elementary mathematics learning.

Practically, this instrument can be used by lecturers and teacher education programs to map PGSD students' readiness to integrate AI into mathematics instruction. The results of the measurement may serve as a basis for designing training programs, workshops, or course improvements that emphasize the ethical and pedagogical use of AI. In addition, the instrument may help teacher education programs identify which dimensions of competence still need strengthening, whether in content, pedagogy, technology, or AI-related integration. In this regard, the AI-TPACK instrument has strategic value for supporting the improvement of prospective elementary teachers' quality.

Nevertheless, this study has several limitations. First, the testing of the instrument was conducted within a specific context and with a particular group of participants, so the generalizability of the findings should be considered with caution. Second, the instrument mainly focuses on self-assessment, which means that future studies should combine it with performance observation, task-based assessment, or authentic assessment in order to obtain a more comprehensive picture of competence. Third, the factor structure of the instrument may be further strengthened through larger and more diverse samples across institutions. Despite these limitations, the findings still demonstrate that the developed instrument meets the basic requirements of a feasible measurement tool.

Overall, the results and discussion confirm that the AI-TPACK instrument developed in this study has good quality and is feasible for measuring PGSD students' competence in mathematics learning. These findings also reinforce the importance of AI-TPACK development as part of preparing prospective elementary school teachers who are adaptive to the digital transformation of education

4. CONCLUSION

Based on the results of the study, it can be concluded that the AI-TPACK instrument developed for students of the Primary School Teacher Education Program (PGSD) in mathematics learning has met the feasibility criteria as a measurement tool. The instrument was successfully developed through systematic stages, beginning with needs analysis, followed by the formulation of indicators and items, expert validation, and empirical testing. The findings showed that the instrument demonstrated good content validity, adequate construct validity, high reliability, and acceptable item quality. Therefore, this study answers the research questions by showing that the development of an AI-TPACK instrument for PGSD students in mathematics learning can be carried out systematically and can result in a valid and reliable measurement tool. In addition, the developed instrument was able to represent the dimensions of competence involving the integration of *artificial* *intelligence*, pedagogy, technology, and mathematical content, so that it can be used to map PGSD students' readiness to respond to the demands of learning in the digital era.

Based on these findings, it is suggested that lecturers who teach mathematics learning, microteaching, and instructional planning courses use this instrument as a tool to identify the level of PGSD students' readiness to integrate AI into mathematics instruction. For PGSD study programs, this instrument may serve as a basis for designing curriculum enhancement, training, or workshops that focus on the pedagogical, critical, and ethical use of AI. For future researchers, it is recommended that this instrument be tested on broader and more diverse samples, including students from different universities, in order to obtain stronger empirical evidence regarding the stability of the instrument's construct. In addition, future studies may further develop this instrument into a performance-based assessment or combine it with observation and task-based evaluation, so that the measurement of AI-TPACK competence is not only based on self-perception but also reflects the actual performance of prospective teachers in instructional practice

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