Development and Validation of an AI Literacy Scale for Pre-Service Teachers in Thailand

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Abstract: Artificial intelligence (AI) is having a significant impact on contemporary lives, especially in learning and instruction design. The exploration of AI literacy in teacher education is an essential foundation for the redesign of instructional approaches to enhance pre-service teachers' AI literacy. This study aimed to develop the scale of AI literacy by employing exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to develop the items and validate a self-assessment AI literacy scale for pre-service teachers for practical implementation for teacher development courses in undergraduate curricula. In this study, AI literacy, synthesized from relevant studies and drawing on experts in educational technology, includes four constructs: 1) recognition, 2) fundamental comprehension, 3) pedagogy, and 4) ethical use of AI, offering a comprehensive and versatile instrument for the measurement of AI literacy in teaching professional development. The instrument's reliability and construct validity were confirmed using statistical analyses of data collected from 1,673 undergraduate pre-service students studying teaching and education at Thai universities, including both public and private universities. The findings indicated that the four constructs proposed had a good fit and showed excellent internal consistency ($\alpha = 0.94$). The average variance extracted, and composite reliability (CR) values met the criteria for validity. In the EFA, the items were reduced from 42 items to 39 items, which had a Kaiser-Meyer-Olkin of 0.993 and a significant test of sphericity (p-value < .0001). The CFA results revealed a chi-Square value of 480 ($p < 0.001$), an RMSEA of 0.035, an SRMR of 0.022, a comparative fit index (CFI) of 0.974, and a GFI of 0.974. Thus, the AI literacy scale for pre-service teachers developed in this study is a valid and reliable instrument for assessing pre-service teachers' AI literacy. Although it was not yet implemented in classroom settings, the established validity and reliability of the scale provide a foundation for future research and practical applications in teacher education.

Keywords: AI literacy for teacher, AI for teacher development, AI for education, Pre-Service teachers, Teacher education, Confirmatory factor analysis

1. Introduction

The cutting-edge of digital technologies, in particular in the case of artificial intelligence (AI) technology, has significant impacts on people's means of working and designing instruction in the twenty-first century (Kanont, et al., 2024; Ng, et al., 2021b; UNESCO, 2023; Wong, et al., 2020). Generative AI (Gen-AI) refers to artificial intelligence which, capable of producing muti-type content such as text, images, audio, or video. Hence, the widespread usage of Gen-AI applications among learners and instructors heavily plays a role in shifting contemporary learning and teaching norms, including the opportunities, imperatives, and risks that are inherent to the use of Gen-AI (Ajevski, et al., 2023; Bastani, et al., 2024; Oster, Henriksen and Mishra, 2024). Consequently, the future of educators necessitates the design of learning and integration with digital technology to align with the relevant and important needs of present society (Anders, 2023; Chen and Lin, 2023; Weston, 2023). Thus, pre-service teachers across multiple fields require the development of AI literacy, one of the future digital competencies of the framework for educators (UNESCO, 2023; Vuorikari, Kluzer and Punie, 2022). In addition, AI literacy is aligned with The National AI Action Plan for Thailand's Development (2022–2027), which is intended to develop human resource skills in AI for teachers, lecturers, and students, leading to improvements in the economy and in quality of life of the people by 2027 (Ministry of Higher Education, 2023).

Recent research has endeavored to evaluate AI literacy and to develop key components of AI literacy, e.g., Dai, et al. (2020), Ng, et al., (2021a), Davy Tsz Kit, et al. (2022), Wang, Rau and Yuan, (2022), Williams, et al. (2022) Biagini, Cuomo and Ranieri (2023), and UNESCO (2024). Then, several studies presents AI literacy relates to the recognition and distinguishing the content or systems that use AI using knowledge, concepts, and basic understanding of AI technology, the ability to use AI in various contexts, and the critical evaluation and selection of AI that is appropriate to a given issue or problem, under the ethical framework of the use of AI. However,

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while several researchers have studied AI Education, it was found that most research relates to the development of K-12 AI curriculum, which refers to the formal methods, courses, and pedagogical strategies used to achieve that goal (Eguchi, Okada and Muto, 2021; Jang, Jeon and Jung, 2022; G. Steinbauer, et al., 2021), while AI literacy emphasize on critically aware, recognize, evaluate, communicate, collaborate with, and use AI technologies responsibly in education.

To address this gap, the present study develops and validates an AI literacy scale for pre-service teachers to capture their knowledge, attitudes, and readiness to integrate AI in educational contexts. The scale aims to support teacher education programs in enhancing AI literacy and technology-enhanced learning practices. This study draws upon recently introduced frameworks and instruments (Ng, Wu, et al., 2023; Zhao, Wu and Luo, 2022) designed to measure AI literacy across four dimensions: affective, behavioral, cognitive, and ethical. Following these frameworks, the current study operationalized AI literacy using these four dimensions and employed exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to validate the structure of the scale for pre-service teachers. Two research questions guided the study:

RQ1: What constructs and factors of an AI literacy scale for pre-service teachers?

RQ2: Is the AI literacy scale for pre-service teachers reliable and valid?

Overall, the findings of this study help support the development of an AI literacy scale that takes into account recent AI developments and is relevant to undergraduate pre-service teachers and teacher education in higher education. In addition, applications could be beneficial for developing learning, establishing, and integrating practical AI methods of instruction, and implementing policies to improve AI abilities and support future AI proficiency in pre-service teachers.

2. Literature Review

2.1 AI in Teacher Education

AI is widely utilized worldwide, in particular large language models (LLMs), which are the foundation of current Gen-AI. LLMs have been applied in various industries to generate media and information to enhance user productivity, such as consultation, learning, and decision-making in multiple fields (Burgsteiner, Kandlhofer and Steinbauer, 2016; Ghallab, 2019; Ng, et al., 2021a). Recent studies and emerging trends show that AI for education can assist teachers in teaching and learning, including in designing instruction, delivering lessons, generating educational media, providing personalized feedback, and enhancing professional development (Fernández Jiménez, 2024; Kim, 2024; Younis, 2025). AI thus can process vast amounts of data and information that go far beyond human capabilities. AI can learn and generate new content across various types of media, identify patterns in data, and facilitate human decision-making with predictive analytics (Hwang, et al., 2020; Ng, et al., 2021a; UNESCO, 2024). The integration of AI into teacher education will improve education and enable new forms of teaching, learning, and educational management, enhancing learning experiences and supporting teacher tasks. For instance, AI-driven adaptive learning systems can personalize educational content and make it more suitable for student needs, increasing learning engagement and improving learning outcomes and skills (Ahmad, et al., 2022; Davy Tsz Kit, et al., 2022; Sukkeewan, Songkram and Nasongkhla, 2024). In addition, AI tools can help teachers develop professional competencies through the provision of real-time feedback, analytics on student performance, and access to and generation of in-time educational resources, including through edcafe.ai, ChatGPT, Fliki, DALL-E, Botnoi, Gemini Code Assist, etc. (Chaudhry and Kazim, 2022). At present, AI, Gen-AI in particular is reshaping the educational landscape and redefining educators' competencies. As noted, a concerted effort is required to develop AI literacy in teacher education to ensure that teachers can effectively integrate technologies into their pedagogical practices (Seo, et al., 2021). Understanding and leveraging the capabilities of AI is becoming increasingly important for educators who intend to enhance learning experiences for their students and prepare them for a future where AI plays a significant role (Markauskaite, et al., 2022; Davy Tsz Kit, Ng et al., 2023).

2.2 Definitions and Components for AI Literacy in Pre-Service Teachers

AI literacy is increasingly being conceptualized as a multifaceted construct in teacher education that combines a technical understanding of AI with practical and ethical competencies. On the one hand, AI literacy includes technical knowledge, such as, the ability to explain how machine learning algorithm's function and the ability to understand the basic techniques and concepts behind the AI that is embedded in modern tools. This technical perspective aligns with calls for teachers, especially teachers of computer skills or technology teachers, to grasp what makes up AI and how it operates (Chiang and Yin, 2022; Kandlhofer, et al., 2016; Kong, Man-Yin Cheung

and Zhang, 2023). In addition, AI literacy also entails having practical skills and ethical awareness, including the use of AI-driven applications in the classroom and critical evaluation of AI outputs and impacts. Researchers have shown that AI-literate educators should be able to leverage AI as a teaching assistant as well as recognizing its limitations and adhering to principles of fairness, transparency, and responsibility. Thus, pre-service teachers need to have a balance of both perspectives: a solid foundation in how AI works and sufficient discernment to apply AI tools pedagogically and ethically (Hua Du, et al., 2024; Kong, Man-Yin Cheung and Zhang, 2021; Long, Blunt and Magerko, 2021; Ng, et al., 2021a; Gerald Steinbauer, et al., 2021). In this study, the authors adopt a definition of AI literacy that refers to its general applicability and specify it for teacher education. This includes having fundamental knowledge and understanding of AI technology, critically and appropriately applying AI technology in pedagogy, and remaining aware of its ethical impacts and its proper use in the present societal and educational context, including ethical unitization (Hua Du, et al., 2024; Ng, et al., 2021a; Ng, et al., 2023a; UNESCO, 2024; Wilton, Sharma and Fan, 2022; Zhao, Wu and Luo, 2022). This concept is also suitable for teaching professionals who are not involved in AI development and AI scientists who use AI as an educational assistant tool.

The recently research on the components of AI literacy has shown that many researchers have proposed different components for it in relation to various contexts and study objectives, including AI awareness, knowing and understanding AI, using AI, evaluating and creating AI, and AI ethics (Davy Tsz Kit, et al., 2022; Ng, et al., 2021a; Ng, et al., 2023b), which is based on the digital literary concept. While, several studies have examined the structure of AI literacy, which involves several dimensions and definitions of AI literacy in various settings through employing qualitative and quantitative methods (Pinski and Benlian, 2023; Yetişensoy and Rapoport, 2023; Zhao, Wu and Luo, 2022). In the other perspective UNESCO (2024) defines 15 competencies across five domains, notably, AI foundations and applications, AI pedagogy, and the ethics of AI. These domains emphasize that teachers must have a solid understanding of what AI is and how it works, strategies of integrating AI into teaching practice, and a strong commitment to the ethical use of AI in education. This global policy perspective validates the inclusion of AI recognition, AI fundamental comprehension, AI pedagogy, and AI ethical use as crucial dimensions for the preparation of teachers. Moreover, Ng, et al. (2021c) and Ng, et al. (2023b) conducted an exploratory review of the AI literacy literature, distilling four overarching aspects of AI literacy: knowing and understanding AI, using and applying AI, evaluating and creating with AI, and addressing ethical issues. Similarly, Wang, Rau and Yuan (2022). in the course of developing an AI literacy scale, partitioned AI literacy into four factors: awareness of AI, practical skills in using AI, critical evaluation of AI outputs, and understanding AI ethics. Celik (2023b) argued that to effectively integrate AI into education, teachers must go beyond developing technological knowledge of AI to create pedagogical strategies for the use of AI, combined with the ability to address ethical issues to do with AI. In that study, an AI literacy scale was developed to measure teachers' knowledge for the instructional use of AI, extending Technological Pedagogical Content Knowledge (TPACK) including explicit ethical considerations. The results of this process showed that greater knowledge of how to interact with AI tools leads to a better understanding of AI pedagogical contributions, and pure technical knowledge needed to be coupled with pedagogy to be meaningful.

The findings indicated that the authors were motivated to extend the existing framework through integrating concepts of AI literacy (Ng, et al., 2021a; Ng, et al., 2021c; Wang, Rau and Yuan, 2022), the TPACK-AI framework (Celik, 2023b; Kim, et al., 2021), and the AI competency (UNESCO, 2024); which emphasis muti-levels of AI knowledge and skills based on human-centric, teacher development and responsibilities toward AI; for to teacher education contexts, in particular in various field of study in pre-service contexts, including the recognition, fundamental comprehension, pedagogy, and AI ethical use of AI. Hence, the researchers synthesized and conceptualized four aspects of AI literacy for pre-service teachers identified from the reviews.

AI Recognition refers to the acknowledgment of the comprehensive potential and impact of AI in educational settings. It involves an overview of the concept of AI processes in applications and services that critically distinguishes between human- and AI-generated content and explains the reasons for these distinctions. AI recognition entails a self-reflective process that occurs both before and after engagement with AI technology, as highlighted in several studies (Celik, 2023a; Laupichler, et al., 2022; Lee, et al., 2021; Wang, Rau and Yuan, 2022; Yetişensoy and Rapoport, 2023). According to this process, learners can critically assess their recognition of AI capabilities and limitations before its use. Before utilizing AI tools, learners contemplate the impact those AI tools can have on learning design, teacher tasks, and the teaching profession. The postunitizing learner's reflection allows them to identify misconceptions, understand AI's effects on their cognitive processes, and make informed adjustments for the case of future interactions.

Fundamental Comprehension of AI refers to the capacity to explain the essential workings of AI and classify several types of AI that may be useful for educational management. This incorporates articulation of the functions of specific AI technologies, reasoning concerning AI-generated content, identifying the advantages and precautions that are associated with AI usage, and discussing AI-related issues that impact teaching and education (Celik, 2023a; Davy Tsz Kit, et al., 2022; Laupichler, et al., 2022; Lee, et al., 2021; Ng, et al., 2021a; Williams, et al., 2022). This would include understanding such fundamental concepts as machine learning, the basic techniques behind AI products and service processes, LLMs, and various types of AI in the educational landscape. In line with this, Kim and Kwon (2023) emphasized that educators should have a basic understanding of AI in the TPACK framework used for elementary teachers. Moreover, for computer science teachers, Kim, et al. (2021) suggested that the requirements for K-12 teacher competencies in AI education should include the ability to construct programming environments, use web or API-based online education platforms for use in AI project education, and understand the fundamentals of AI, computer science, and applied mathematics, together with AI ethics. These competencies ensure that teachers are sufficiently well-equipped to integrate AI concepts into their curricula and guide students as they navigate the evolving technological landscape.

AI Pedagogy with reference to AI involves integration into teaching and learning to address educational problems and enhance instructional outcomes. Such integration includes demonstration of the use of AI in various educational contexts, the effective management of AI tools in both classroom and online environments, and the promotion of practical and ethical AI usage in learners (Celik, 2023b; Dai, et al., 2020; Davy Tsz Kit, et al., 2022; Kim, et al., 2021; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023). Moreover, Celik (2023b) and Kim, et al. (2021) suggested that the enhancement of AI integration in pedagogy can be achieved through use of the AI-TPACK framework, which supports learners in its use of and becoming familiar with AI technologies in their application in teaching practices and strategies. This framework offers AI tools that are embedded in the learning ecosystem that enable educators to integrate AI directly into the educational experience for enhanced learning outcomes.

AI Ethical Use of AI refers to acting in a way that is critically aware of and in adherence to ethical frameworks that govern the use of AI in educational institutions, together with complying with government policies and service provider guidelines. This includes the following terms of use for the use of AI-generated content and management of data for AI processing without violating institutional regulations (Celik, 2023a; Kong, Man-Yin Cheung and Tsang, 2022; Laupichler, et al., 2022; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023). Moreover, Khammarnia, et al. (2022) note that professional ethics include commitment and conscientiousness toward an individual's work, responsibilities, and commitments, as influenced by knowledge, desire, capability, and attitudes. These ethical considerations relate to rational thinking process that enables individuals to discern the values that should be preserved and disseminated in an organization. In particular, H. Du, et al. (2024) showed that AI ethics, including transparency, responsibility, justice, and sustainability, indirectly influence the behavioral intention to learn AI and directly affects teachers' perceptions of the use of AI for social good. Further, pre-service teachers should learn that their professional judgment and values are crucial for AI use. They need to understand the relevant ethical principles (e.g., fairness, nondiscrimination, and privacy) and should be prepared to apply them in the use of AI tools (UNESCO, 2024). Studies have found that teachers at present do not have sufficient training in these areas. In a recent study, pre-service teachers voiced concerns regarding data privacy and algorithmic bias as critical issues (Kohnke, et al., 2025). To respond to this, a large number of ethical principles or guidelines for teachers and educators have been developed to promote the proper understanding and use of AI (Richards and Dignum, 2019; U.S. Department of Education, 2023; UNESCO, 2023).

Previous findings have suggested that scholars were motivated to extend existing frameworks by integrating AI literacy concepts (Ng, et al., 2021a; Wang, Rau and Yuan, 2022), TPACK-AI framework (Celik, 2023b; Kim, et al., 2021), and the AI competency framework of UNESCO (2024) to teacher education contexts, in particular in various fields of study in pre-service contexts, including 1) AI recognition, 2) AI fundamental comprehension, 3) AI pedagogy, and 4) AI ethical use. Researchers have thereby developed four constructs for AI literacy for pre-service teachers. The theorical definitions of the constructions are presented in Table 1. Following this, the authors plan to validate these proposed constructs by assessing the reliability and validation of the AI literacy scale serve as an instrument to measure preservice teachers' AI literacy levels within teacher education.

While previous studies have proposed multiple frameworks and dimensions for AI literacy, this study focuses on four key factors; AI Recognition, AI Fundamental Comprehension, AI Pedagogy, and AI Ethical Use; because these dimensions consistently appear across the most influential frameworks (Ng et al., 2021a; Wang et al., 2022; Celik, 2023b) and align with the professional competencies among pre-service teachers. The selection of these

four factors reflects both theoretical parsimony and contextual relevance for pre-service teacher education. Given that these constructs were conceptually derived from well-validated international frameworks, a confirmatory rather than exploratory approach was employed to evaluate their applicability within this context. The theoretical definitions of the constructions are presented in Table 1.

Table 1: Summary definitions of AI literacy for pre-service teachers

AI literacy	Definitions
AI recognition (RECO) (Celik, 2023a; Laupichler, et al., 2022; Lee, et al., 2021; Wang, Rau and Yuan, 2022; Yetişensoy and Rapoport, 2023)	Ability to recognize the potential and scope of AI that can be beneficial, understand its impacts, and appreciate its importance in general and educational scope. This includes identifying the fundamental processes of AI technology when using applications or services derived from AI implementation, critically distinguishing between content created by humans and that generated by AI, providing reasons for such distinctions.
AI fundamental comprehension (COMP) (Celik, 2023a; Davy Tsz Kit, et al., 2022; Laupichler, et al., 2022; Lee, et al., 2021; Ng, et al., 2021a; Williams, et al., 2022).	The capability to explain the basic working processes of AI and classify the types of AI that can be utilized in educational management. This would involve stating the functions that specific AI technologies can perform, offering reasoning when observing content produced by AI, identifying the advantages and precautions of AI usage for others, and discussing issues related to AI that affect teaching management and educational settings.
AI pedagogy (PEDA) (Celik, 2023b; Dai, et al., 2020; Davy Tsz Kit, et al., 2022; Kim, et al., 2021; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023).	The ability to proceed through the process of integrating AI into the design or solution to problems in teaching and learning management. This includes demonstrating examples of using AI in various educational contexts, managing, and controlling the use of AI in both classroom and online learning environments, and promoting practical and ethical AI usage among learners.
AI ethical use (ETHIC) (Celik, 2023a; Kong, Man-Yin Cheung and Tsang, 2022; Laupichler, et al., 2022; Ng, et al., 2021a; Wang, Rau and Yuan, 2022; Williams, et al., 2022; Yetişensoy and Rapoport, 2023)	The ability to employ AI morally, fairly, and transparently in full compliance with institutional regulations, government policies, and any usage restrictions imposed by AI service-providers while actively detecting and mitigating algorithmic bias, safeguarding privacy, and copyright, and retaining clear human accountability for AI-driven decisions. This requires teachers to observe formal terms-of-use (e.g., data-handling, academic-integrity, and content guidelines), to interrogate AI outputs for potential inequities or harms, and to ensure that all students benefit equitably from AI under explicit human oversight.

3. Method

In this study, the authors applied the scale development and validation research approach presented by Boateng et al. (2018) to develop an AI literacy scale for students in education. The approach consists of four phases: Phase 1: item development, to define domain boundaries, generate suitable questions, and evaluate item representativeness for the target population; Phase 2: questionnaire implementation, to ensure accurate data collection and data availability for scale validation; Phase 3: item reduction, to identify the optimal factor structure for the item set; and Phase 4: construct validity, to examine latent structures and relationships among items.

The population of this study comprised pre-service teachers enrolled in teacher education programs across universities in Thailand. A stratified random sampling method was used to ensure representation from the from four groups of universities in Thailand. The target sample size was calculated using the Soper (2022) online calculator, with the following parameters: anticipated effect size = 0.1, desired statistical power level = 0.8, number of latent variables = 5, number of observed variables = 14, and probability level = 0.05. The calculation yielded a recommended minimum sample size of 1,599 participants.

In this research, data were analyzed using SPSS V.29.0 and Jamovi V.2.3 to explore descriptive and factor analyses. Factors were analyzed using EFA, and structural validity was established using confirmatory factor analysis (CFA). The Goodness of Fit Index (GFI) was assessed in this study, along with Root Mean Square Error of Approximation (RMSEA), comparative fit index (CFI), and Adjusted Goodness-of-Fit Index (AGFI). As literature indicates, when a model's CFI, GFI, and AGFI values are more than 0.95, this represents an excellent fit. Likewise, the value for RMSEA, which was below 0.05, also indicated an excellent fit. (Fan, Thompson and Wang, 1999; Hair, et al., 2018; Jöreskog and Sörbom, 1986; MacCallum, Browne and Sugawara, 1996; Tabachnick and Fidell, 2013). The research procedures and results for each research phase were presented as follows.

3.1 Results

3.1.1 Phase 1: Item development

In this phrase, all of the AI literacy scale items were created through synthesizing the educational technology literature, international organization reports, and relevant research in both international and national contexts, and then they were adjusted by the researchers according to the theoretical definitions for each construct (Table 1) and all of the items are listed in the Appendix. Eight experts in the field of educational technology and communications then reviewed the items for their wording and quality of the items to minimize misperceptions. The experts also assessed the items' content validity to align with the theoretical definitions. Then, the authors have reviewed and edited AI literacy scale items as the experts recommend. Following this, the researchers conducted a pilot test of the measurement instrument in a sample of 30 students to verify the items' clarity and make appropriate adjustments to align with the context of pre-service teachers studying in Thailand. Cronbach's alpha coefficients were calculated for each construct, which helped verify the items' internal consistency, where values above 0.7 were considered acceptable and ready for next phase implementation. Cronbach's alpha values for internal consistency and reliability obtained from the data analysis for each construct were as follows: AI recognition = 0.941, AI fundamental comprehension = 0.971, AI pedagogy = 0.962, and AI ethical use = 0.966.

The research instrument used was an online survey questionnaire administered using JotForm. This instrument was designed to gather data for the study and was divided into two parts. Part 1 focused on the collection of demographic information from the sample, and Part 2 focused on the collection of AI literacy items. These were 42 items formatted to the 7-point level of agreement on a Likert scale ranging from "totally disagree" (1) to "totally agree" (7). (Likert, 1932; Vagias, 2006). A 7-point Likert scale was used to provide finer distinctions in participants' perceptions and enhance measurement reliability (Preston, C., and Colman, A., 2000). In the initial scale, there were 9 items for AI recognition, 12 items for AI fundamental comprehension, 9 items for AI pedagogy, and 12 items for AI ethical use, total were 42 items.

3.1.2 Phase 2: Questionnaire implementation

As the results, Between Q3 and Q4 of 2024, the research team distributed digital questionnaires to pre-service teachers across universities in various regions of Thailand. The survey was shared through selected academic units or departmental contacts within each university or faulty. Within these units, students were invited to participate on a voluntary basis, and responses were collected from those who chose to complete the questionnaire. Before conducting the analysis, data cleaning procedures were applied to identify missing values, and remove inconsistent responses by examining straight-lining behavior. The results are 1,673 higher education students studying in education departments or faculty across the from four groups of universities in Thailand, concentrating in the following areas: 1) global and frontier research, 2) technology development and innovation, 3) area-based and community engagement, and 4) private and other. Among these samples, 570 were men (34.07%), and 1,103 were women (65.93%); 487 (29.11%) were first-year students, 654 (39.09%) were sophomores, 312 (18.65%) were juniors, and 220 (73.33%) were seniors. Most participants were studying at area-based and community engagement universities (n = 776, 46.38%), technology development and innovation universities (n = 464, 27.73%), global and frontier research universities (n = 276, 16.50%), and private and other universities (n = 157, 9.38%).

3.1.3 Phase 3: Item reduction

Item reduction was designed to ensure that sufficient items representing the four AI literacy constructs were retained, providing evidence of construct validity (Hinkin, 1998). A reduction in the number of items can also enhance the usability of the scale in various contexts, such as in the teaching profession. For this, we conducted an EFA. EFA is used to uncover fundamental structures in multivariate observed variables and to address dimensionality reduction. Thus, EFA can condense a set of variables that show complex interrelationships into a few core factors. We calculated item-total correlations to select the most appropriate items for the four constructs.

We initially evaluated the suitability of the data for factor analysis using the Kaiser-Meyer-Olkin (KMO) test, which produced a sampling adequacy measure of 0.993. This value exceeds the recommended threshold of 0.95, thereby confirming that the data were appropriate for use in EFA. Moreover, Bartlett's test of sphericity found significant differences from an identity matrix (p-value < .0001), and the cumulative value was 73.786, which shows a greater than 60% share of the total variance explained by the factors (Hair, 1998). Therefore, we conducted four-factor EFA utilizing maximum likelihood estimation and varimax rotation with Kaiser

normalization. This procedure was intended to verify that the items corresponded with the theoretical framework for each construct and to detect any items loaded on multiple factors. The results revealed that three items (PEDA 9, RECO 9, and PEDA 1) loaded on multiple factors. The three cross-loaded items showed semantic overlap across constructs, indicating conceptual rather than data issues; prior studies did not specify their original loadings.The outcomes of the EFA are presented in *Table 2*.

Table 2: Results of exploratory factor analysis

	ETHIC	COMP	RECO	PEDA		ETHIC	COMP	RECO	PEDA
ETHIC 7	**0.721**				**RECO 7**			**0.502**	
ETHIC 6	**0.712**				**RECO 3**			**0.655**	
ETHIC 10	**0.692**				**RECO 1**			**0.648**	
ETHIC 11	**0.687**				**RECO 2**			**0.642**	
ETHIC 4	**0.680**				**RECO 5**			**0.603**	
ETHIC 3	**0.675**				**RECO 6**			**0.588**	
ETHIC 12	**0.668**				**RECO 4**			**0.570**	
ETHIC 5	**0.665**				**RECO 8**			**0.525**	
ETHIC 2	**0.662**				**PEDA 7**				**0.571**
ETHIC 8	**0.643**				**PEDA 4**				**0.556**
ETHIC 9	**0.635**				**PEDA 5**				**0.553**
ETHIC 1	**0.601**				**PEDA 3**				**0.553**
PEDA 9	0.519				**PEDA 2**				**0.538**
COMP 3		**0.729**			**PEDA 6**				**0.534**
COMP 5		**0.684**			**PEDA 8**				**0.522**
COMP 6		**0.682**			PEDA 1				0.472
COMP 9		**0.678**							
COMP 8		**0.673**							
COMP 4		**0.671**							
COMP 7		**0.668**							
COMP 2		**0.654**							
COMP 1		**0.581**							
COMP 12		**0.576**							
COMP 11		**0.567**							
COMP 10		**0.527**							
RECO 9		0.524							

Note. Extraction Method: Maximum Likelihood. Rotation Method: Varimax with Kaiser Normalization.

Bartlett's Test of Sphericity; $p < .0001$, Model Fit Measures; root mean square error of approximation (RMSEA) is 0.0333,

Next, the authors used CFA, which leverages sample data to validate a hypothesized factor structure that is based on a theoretical framework. In CFA, the factor structure that was established in existing theories enables us to create an estimated covariance matrix. The researchers performed CFA on each subscale to assess the factor loadings that are associated with their respective constructs. In addition, we calculated item-total correlations, seeking to identify items deviating from the overall response patterns. Factor loadings and item-total correlation coefficients for each of the four constructs are presented in Table 3. We selected items using the following criteria: (a) factor loadings in EFA exceeding 0.50 within their factor group, (b) factor loadings in CFA greater than 0.30 (Costello and Osborne, 2005), and (c) item-total correlation coefficients above 0.60 (Hair, 1998). The researchers thereby eliminated three items that did not meet the criteria and were loaded with multiple constructs. We then refined the scale to exclude three items from constructs, resulting in 39 items as the revised scales selected from the 42 initial items.

Table 3: Descriptive statistics and principal factor analysis results

	Mean	S.D.	α	Loading	Item-total correlation		Mean	S.D.	α	Loading	Item-total correlation
RECO 1	5.64	1.343	0.954	0.741	0.706	PEDA 1	5.53	1.364	0.937	0.730	0.695
RECO 2	5.44	1.346	0.952	0.771	0.732	**PEDA 2**	5.37	1.314	0.934	0.792	0.754
RECO 3	5.66	1.355	0.952	0.768	0.728	**PEDA 3**	5.40	1.315	0.932	0.818	0.776
RECO 4	5.29	1.387	0.953	0.794	0.754	**PEDA 4**	5.39	1.356	0.933	0.808	0.763
RECO 5	5.40	1.341	0.952	0.807	0.763	**PEDA 5**	5.41	1.372	0.931	0.837	0.795
RECO 6	5.38	1.371	0.952	0.791	0.751	**PEDA 6**	5.41	1.333	0.934	0.792	0.757
RECO 7	5.32	1.411	0.952	0.797	0.763	**PEDA 7**	5.38	1.385	0.933	0.804	0.757
RECO 8	5.40	1.380	0.952	0.792	0.756	**PEDA 8**	5.35	1.360	0.932	0.822	0.783
RECO 9	5.38	1.396	0.952	0.800	0.773	PEDA 9	5.47	1.325	0.935	0.785	0.754
COMP 1	5.32	1.427	0.954	0.765	0.740	**ETHIC 1**	5.44	1.419	0.953	0.779	0.757
COMP 2	5.18	1.379	0.952	0.810	0.775	**ETHIC 2**	5.43	1.370	0.952	0.807	0.761
COMP 3	5.15	1.464	0.952	0.802	0.748	**ETHIC 3**	5.47	1.349	0.951	0.818	0.771
COMP 4	5.26	1.385	0.953	0.788	0.746	**ETHIC 4**	5.45	1.306	0.952	0.812	0.765
COMP 5	5.23	1.390	0.952	0.825	0.785	**ETHIC 5**	5.41	1.354	0.952	0.814	0.777
COMP 6	5.22	1.397	0.952	0.805	0.756	**ETHIC 6**	5.50	1.342	0.952	0.791	0.732
COMP 7	5.33	1.396	0.952	0.819	0.784	**ETHIC 7**	5.47	1.360	0.951	0.822	0.766
COMP 8	5.26	1.384	0.952	0.807	0.764	**ETHIC 8**	5.45	1.359	0.952	0.798	0.765
COMP 9	5.28	1.407	0.952	0.816	0.770	**ETHIC 9**	5.42	1.361	0.952	0.803	0.764
COMP 10	5.41	1.325	0.953	0.778	0.766	**ETHIC 10**	5.49	1.387	0.952	0.801	0.742
COMP 11	5.40	1.364	0.952	0.812	0.792	**ETHIC 11**	5.47	1.330	0.952	0.798	0.746
COMP 12	5.39	1.391	0.952	0.811	0.797	**ETHIC 12**	5.57	1.342	0.952	0.785	0.737

3.1.4 Phase 4: Construct validity

In our assessment of our measurement model, all the factors had high correlations that were above 0.8, as shown in *Table 4*. The constructs presented varying degrees of fit. AI recognition showed a satisfactory fit, with chi-square = 144, df = 27, $p < 0.001$, RMSEA = 0.064, and SRMR = 0.021, along with good fit indices, including CFI = 0.981, GFI = 0.996, and AGFI = 0.992. AI fundamental comprehension constructs also indicated good model fits, with chi-square = 203, df = 54, $p < 0.001$, RMSEA = 0.051, and SRMR = 0.017, along with good fit indices, including CFI = 0.985, GFI = 0.995, and AGFI = 0.991. AI pedagogy showed a satisfactory fit, with a chi-square = 65, df =14, $p < 0.001$, RMSEA = 0.059, SRMR = 0.014, and good fit indices, including CFI = 0.990, GFI = 0.998, and AGFI = 0.996. AI ethical use showed a satisfactory fit, with a chi-square =199, df = 54, $p < 0.001$, RMSEA = 0.051, SRMR = 0.017, and good fit indices including CFI = 0.985, GFI = 0.995, and AGFI = 0.992.

Table 4: Descriptive statistics and Pearson correlations among factors

	Mean	SD	Aware	Know	Apply	Ethic
RECO	5.66	0.993	-			
COMP	5.58	1.011	0.858	-		
PEDA	5.62	0.986	0.820	0.866	-	
ETHIC	5.70	0.969	0.840	0.827	0.838	-

Table 4 presents convergent and divergent validity assessed using CFA with the measurement model, and CA and composite reliability (CR) tests were performed to assess reliability. CA measured the internal consistency among items, as seen in Table 5, and CR was used to describe the extent to which a train of items could represent potential constructs. The CR values ranged from 0.956 to 0.931, the factor loading ranged from 0.924 to 0.955, and, finally, the AVE values for the variables ranged from 0.616 to 0.658. DeVellis (2012); Fornell and Larcker (1981) suggested that, where AVE is above 0.50 and CR is above 0.70, the convergent validity of the construct is

satisfactory. The values of Cronbach's alpha for these findings for the four constructs were AI Recognition (RECO) = 0.928, AI Fundamental Comprehension (COMP) = 0.956, AI Pedagogy (PEDA) = 0.931, and AI Ethical Use (ETHIC) = 0.956, respectively. Although each of the four constructs exhibited a reliability of more than 0.70, the instrument itself had a value above 0.80, indicating that the instrument was more reliable than the separate constructs.

Table 5: Results of the measurement model

Latent	Observed	Mean	SD	b(SE)	β	z	p	R^2	α	CR	AVE
RECO	**RECO 1**	5.87	1.204	0.000	0.747			0.558	0.920		
	RECO 2	5.58	1.219	0.041	0.775	25.900	< .001	0.600	0.918		
	RECO 3	5.78	1.194	0.040	0.772	25.800	< .001	0.596	0.918		
	RECO 4	5.56	1.265	0.042	0.796	26.700	< .001	0.633	0.917		
	RECO 5	5.63	1.197	0.040	0.808	27.200	< .001	0.654	0.916		
	RECO 6	5.60	1.226	0.041	0.795	26.700	< .001	0.632	0.917		
	RECO 7	5.62	1.232	0.041	0.795	26.700	< .001	0.632	0.918		
	RECO 8	5.65	1.218	0.040	0.787	26.400	< .001	0.619	0.918		
COMP	**COMP 1**	5.61	1.269	0.000	0.764			0.584	0.954		
	COMP 2	5.43	1.233	0.036	0.810	28.500	< .001	0.656	0.952		
	COMP 3	5.50	1.302	0.038	0.803	28.100	< .001	0.644	0.952		
	COMP 4	5.56	1.216	0.036	0.788	27.500	< .001	0.622	0.953		
	COMP 5	5.51	1.245	0.036	0.825	29.100	< .001	0.681	0.952		
	COMP 6	5.53	1.219	0.036	0.806	28.300	< .001	0.649	0.952		
	COMP 7	5.63	1.251	0.037	0.819	28.800	< .001	0.671	0.952		
	COMP 8	5.55	1.226	0.036	0.807	28.300	< .001	0.652	0.952		
	COMP 9	5.59	1.235	0.036	0.816	28.700	< .001	0.665	0.952		
	COMP 10	5.67	1.170	0.035	0.778	27.100	< .001	0.606	0.953		
	COMP 11	5.68	1.193	0.035	0.812	28.500	< .001	0.659	0.952		
	COMP 12	5.69	1.217	0.036	0.810	28.500	< .001	0.656	0.952		
PEDA	**PEDA 2**	5.57	1.127	0.000	0.790			0.624	0.922		
	PEDA 3	5.61	1.157	0.036	0.815	29.700	< .001	0.664	0.920		
	PEDA 4	5.65	1.177	0.036	0.811	29.600	< .001	0.658	0.920		
	PEDA 5	5.64	1.199	0.037	0.835	30.700	< .001	0.697	0.918		
	PEDA 6	5.63	1.164	0.036	0.795	28.800	< .001	0.632	0.922		
	PEDA 7	5.63	1.193	0.037	0.808	29.400	< .001	0.652	0.920		
	PEDA 8	5.60	1.193	0.037	0.821	30.000	< .001	0.674	0.919		
ETHIC	**ETHIC 1**	5.71	1.260	0.000	0.778			0.606	0.953		
	ETHIC 2	5.65	1.195	0.034	0.807	29.000	< .001	0.652	0.952		
	ETHIC 3	5.70	1.170	0.033	0.818	29.500	< .001	0.670	0.951		
	ETHIC 4	5.67	1.128	0.032	0.812	29.200	< .001	0.659	0.952		
	ETHIC 5	5.63	1.207	0.034	0.814	29.300	< .001	0.662	0.952		
	ETHIC 6	5.71	1.170	0.033	0.792	28.300	< .001	0.627	0.952		
	ETHIC 7	5.69	1.188	0.034	0.822	29.700	< .001	0.675	0.951		
	ETHIC 8	5.70	1.191	0.034	0.798	28.600	< .001	0.637	0.952		
	ETHIC 9	5.69	1.186	0.034	0.803	28.800	< .001	0.645	0.952		
	ETHIC 10	5.71	1.205	0.034	0.802	28.800	< .001	0.643	0.952		

Latent	Observed	Mean	SD	b(SE)	β	z	p	R^2	α	CR	AVE
	ETHIC 11	5.71	1.140	0.033	0.798	28.600	< .001	0.636	0.952		
	ETHIC 12	5.83	1.126	0.032	0.785	28.000	< .001	0.616	0.952		
AI Literacy	**RECO**	5.66	0.993	0.000	0.949			0.900	0.928	0.928	0.616
	COMP	5.58	1.011	0.046	0.955	23.900	< .001	0.912	0.956	0.956	0.646
	PEDA	5.62	0.986	0.041	0.952	24.500	< .001	0.906	0.931	0.931	0.658
	ETHIC	5.70	0.969	0.045	0.924	23.700	< .001	0.853	0.956	0.956	0.644

First, the overall model fit was the theoretical model that was used for AI literacy was acceptable for the fit indicators assessed using multiple fit criteria: seven indices were used, including chi-square/degrees of freedom (df), GFI, AGFI, CFI, and root mean square residual. SEM analysis showed that the goodness of fit statistics of the theoretical framework in Table 6 represented good fit (chi-square = 1,610, df = 698, $p < 0.001$, $\chi2$ /df = 2.30, GFI = 0.974, AGFI = 0.969, CFI = 0.974, RMSEA = 0.035, SRMR = 0.022).

Table 6: Model fit statistics

	Results	Fit Criteria	Result	Reference
χ2	1,610*	p < 0.001	Acceptable	(Hair, et al., 2018)
χ2 /df	2.30	2-5	Acceptable	(Hooper, Coughlan and Mullen, 2007)
RMSEA	0.035	≤ .05	Acceptable	(MacCallum, et al., 1996)
SRMR	0.022	≤ .05	Acceptable	(Hair, et al., 2018)
Comparative Fit Index (CFI)	0.974	≥ .90	Acceptable	(Fan, Thompson and Wang, 1999)
Goodness of Fit Index (GFI)	0.974	≥ .90	Acceptable	(Tabachnick and Fidell, 2013)
Adjusted Goodness of Fit Index (AGFI)	0.969	≥ .90	Acceptable	(Hair, et al., 2018)

The effect was obtained in the research constructs, and the results were as follows: AI recognition (β = 0.949), AI fundamental comprehension (β = 0.955), AI pedagogy (β = 0.952), and AI ethical use (β = 0.924) significantly positively to AI Literacy, as shown in *Figure 1*.

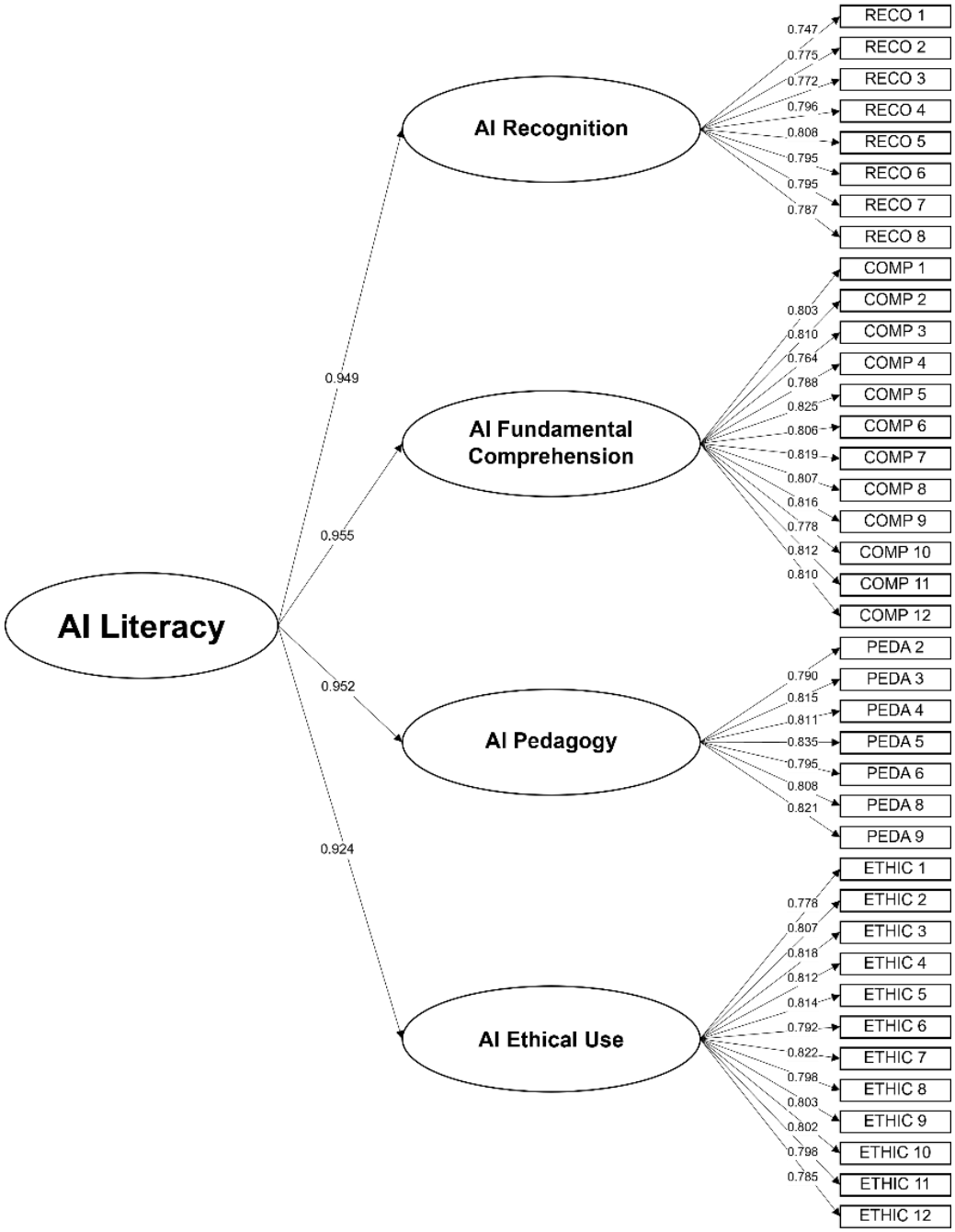

Figure 1: Result of the Confirmatory factor Analysis model

4. Discussion

This study examined AI literacy factors within the context of the teaching profession to develop a measurement instrument for use as a learning progression and self-assessment tool for AI literacy in pre-service teachers and teacher development. This AI literacy in this study includes AI recognition, fundamental AI comprehension, AI pedagogy, and ethical AI use, while other AI literacy scales have generally addressed broader AI literacy or digital skills. The AI literacy factors explicitly integrate pedagogical knowledge and ethical dimensions essential for pre-service teachers and curriculum design for enhancing AI literacy in courses or training (Celik, 2023a, 2023b; Khlaisang and Koraneekij, 2019; UNESCO, 2024; Wang, Rau and Yuan, 2022; Wilson, Scalise and Gochyyev, 2015). The results establish the reliability and validity of the AI literacy scale for both pre-service and in-service teachers. The findings showed that the significant results of the theoretical model comprised four characteristic constructs for the most appropriate conceptualization for AI literacy for teaching and learning. The author would like to present the discussions with the research questions as follows:

RQ1: What constructs and factors of an AI literacy scale for pre-service teachers?

The EFA value for RQ1 revealed a four-factor structure of AI literacy for pre-service teachers: AI recognition, AI fundamental comprehension, AI pedagogy, and AI ethical use, which collectively explained 73.786% of the variance in the data. KMO had an exceptionally high value (0.993), and Bartlett's test of sphericity indicated significant differences ($p < 0.0001$), confirming that the data were suitable for factor analysis. Thus, the scale captures four constructs of AI literacy among pre-service teachers. Each factor represents a different aspect of the ways that pre-service teachers understand and engage with AI. 1) AI recognition and 2) AI fundamental comprehension closely corresponds to the core knowledge and awareness components of AI literacy that have been presented in prior research. During factor analysis, three items were excluded due to overlapping conceptual constructs. The items initially designed to assess AI recognition and AI pedagogy were found to overlap significantly with items on AI ethical use, AI fundamental comprehension, and AI ethical use indicating a need for clearer differentiation in future studies.

This alignment is evident in the comparison of our findings to existing AI literacy frameworks, which commonly include awareness of AI systems and the ability to understand or evaluate AI functionalities (Laupichler, et al., 2023; Wang, Rau and Yuan, 2022). In our findings, AI recognition reflects the teacher's awareness of AI in educational tools and teaching and learning (e.g., recognizing AI applications and their use in educational context), while AI fundamental comprehension reflects a fundamental understanding of AI principles and concepts (e.g., how machine learning works at a basic level). AI pedagogy is a distinct domain that is uniquely important for educators. This factor includes the knowledge and skills that are required to integrate AI into teaching practice and to instruct others concerning AI. From this, it is clear that pre-service teachers recognize that being AI literate goes beyond knowing what AI is or how it works to knowing how to teach with and about AI. These findings are related to existing frameworks of educational technology. It resonates with the concept of TPACK adapted for AI, according to which teachers must blend AI knowledge with pedagogy that can effectively facilitate learning (Kim, et al., 2022). Thus, AI ethical use, indicating that ethical considerations form a key pillar of AI literacy for pre-service teachers, captures an understanding of responsible and principled uses for AI, including questions of fairness, privacy, bias, and social impact in educational settings. This indicates that pre-service teachers are aware of adopting AI in the classroom comes is accompanied by the duty to take moral and safety implications into account.

RQ2: Is the AI literacy scale for pre-service teachers reliable and valid?

CFA was used to address RQ2, producing straightforward evidence that the identified AI literacy constructs are reliably and effectively measured with the developed scale. The factor analyses indicated that the values for AVE and CR values met the thresholds for convergent and construct validity in the measurement model. The reliability for each factor is supported by the high internal consistency, indicated by Cronbach's alpha values well above 0.80. Moreover, the fit statistics of the research model show a good fit: chi-square = 1,610, df = 698, $p < 0.001$, $\chi 2/df = 2.30$, GFI = 0.974, AGFI = 0.969, CFI = 0.974, RMSEA = 0.035, and SRMR = 0.022.

The results of the analyses produce one of the most striking findings in this study, namely, the positive significance shown by all AI literacy constructs as tools as the measurement and learning progress to curriculum or course that integrated AI for education for teacher development. The findings show that teacher preparation programs should adopt a well-rounded, comprehensive approach in incorporating AI into the curriculum, course, or workshop. Instead of treating AI applications as a single skill, learning programs should include several dimensions: raising awareness of AI technologies and their presence, building a basic comprehensive of AI principles, training teachers in the pedagogical application of AI in classrooms, and fostering a strong sense of ethics and responsibility in AI use. Moreover, in designing ethical learning concerning AI, the findings show that blended ethical knowledge, as part of the substantive design of instructional design for AI literacy learning, plays an essential role in the effective utilization of AI (Chan, 2023). To illustrate the result practices from each construct, AI recognition might involve pre-service teachers critically identifying and thinking of AI-generated content and AI-driven tools and used to enhance student engagement, such as adaptive feedback for speech recognition applications. AI fundamental comprehension could manifest as teachers clearly explain to students how recommendation pattern recognition by machine operation and awareness of AI overuse. AI pedagogy might be seen in lessons integrating AI-driven assessments to personalize feedback or using AI-generated content as learning multimedia. Finally, AI ethical use could include teachers facilitating classroom discussions about privacy concerns and critically stimulating students about AI awareness in bias and creative thinking. Furthermore, the validated factor structure provides a framework for the development of AI for education interventions. For instance, if assessment using this scale shows that pre-service teachers, on average, have high

ethical awareness but weaker pedagogical skills with AI, educators could design specific learning modules to enhance pedagogical strategies for the use of AI. Likewise, if the AI recognition rate is low, this could indicate a need to expose teachers to a broader range of examples and cases of AI applications in education. Hence, the scale can diagnose specific strengths and weaknesses, allowing for tailored instructional responses in teacher training. Likewise, Luo et al. (2024) designed AI literacy learning activities that they suggest can be supported with scaffolding tasks that enabled cognitively challenging and emotionally engaging feedback as well as enabling distributed cognition.

5. Conclusions

This study introduced and validated a four-factor model to measure AI literacy among pre-service teachers, providing a theoretically grounded and empirically supported framework for understanding teachers' readiness to integrate AI in education. The developed instrument enables instructional designers, teacher educators, and researchers to systematically assess and enhance AI literacy in teacher preparation programs. Beyond Thailand, the model offers a basis for cross-cultural comparisons and curriculum design that promotes equitable AI competence among future educators. Nevertheless, this study was limited to pre-service teachers in selected institutions, and future research should validate the instrument across broader educational levels and cultural contexts. By moving from conceptual discussions of AI literacy to a validated, evidence-based scale, this research contributes to advancing both theory and practice in AI-integrated teacher education.

5.1 Limitations and Recommendations

The results of this research provide opportunities for researcher to study AI literacy in education or relevant domains for future studies, such as in quantifying baseline AI literacy levels in teacher cohorts, comparing subgroups (e.g., comparing science and technology with humanities and language pre-service teachers), developing comprehensive instructional models for teaching AI literacy for the redesign of courses or curricula in institutions of higher education, and evaluating the impact of new training programs or curricular changes on each aspect of AI literacy. The uses of or scale are not limited to Thailand or to pre-service teachers; it can be adapted and validated for use in other teacher training contexts or with in-service teachers to explore how the construct may vary or hold constant elsewhere.

This study has certain limitations that temper the interpretation of the results. First, the research focused on a single demographic group, which could limit the generalizability of the findings. Then, the data that were collected drew on a cross-sectional design. This means that our results provide a snapshot of AI literacy to participants but do not capture how such competencies could develop or change with additional training or over the course of a teacher's career. Despite these limitations, the design of the study design and our cautious, descriptive interpretation of the scale can ensure that our conclusions are credible and applicable within the stated context.

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AI Ethics statement: The authors declare that they have used AI tools, Grammarly and Quillbot, to enhance the spelling and readability of this manuscript.

Ethics Approval: This paper involved human participants. Ethical permission was obtained from Chulalongkorn University Research Ethics Committee Multi-Institutional Group, set 2: Social Sciences, Humanities, and Fine Arts (reference number 429/67). Written consent was obtained from all participants for both participation and publication (maintaining anonymity). While conducting the research, the researchers followed privacy, data protection, and confidentiality policies. Therefore, all research participants' identities and data remain unidentifiable and will be deleted immediately after the research is completed. All participants consented to the data for research purposes.

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References

Ahmad, S. F., Alam, M. M., Rahmat, M. K., Mubarik, M. S., and Hyder, S. I. (2022). Academic and Administrative Role of Artificial Intelligence in Education. *Sustainability (Switzerland)*, 14(3), 1101. [online] Available at: <https://www.mdpi.com/2071-1050/14/3/1101> [Accessed 27 November 2023].

Ajevski, M., Barker, K., Gilbert, A., Hardie, L., and Ryan, F. (2023). ChatGPT and the future of legal education and practice. *Law Teacher*, [e-journal] 57(3), pp.352-364. https://doi.org/10.1080/03069400.2023.2207426

Anders, B. A. (2023). Is using ChatGPT cheating, plagiarism, both, neither, or forward thinking? Patterns, [e-journal] 4(3), 100694. https://doi.org/10.1016/j.patter.2023.pp.100694

Costello, A. B., and Osborne, J. (2005). *Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. Practical Assessment, Research, and Evaluation*, 10(1). [online] Available at: https://openpublishing.library.umass.edu/pare/article/id/1650/ [Accessed 27 November 2023].

Bastani, H., Bastani, O., Sungu, A., Ge, H., Kabakcı, Ö., & Mariman, R. (2024). Generative AI Can Harm Learning. *The Wharton School Research Paper*. [online] Available at: <https://doi.org/10.2139/ssrn.4895486> [Accessed 27 November 2023].

Biagini, G., Cuomo, S., and Ranieri, M. (2023). Developing and Validating a Multidimensional AI Literacy Questionnaire: Operationalizing AI Literacy for Higher Education. *CEUR Workshop Proceedings*

Boateng, G. O., Neilands, T. B., Frongillo, E. A., Melgar-Quiñonez, H. R., and Young, S. L. (2018). Best Practices for Developing and Validating Scales for Health, Social, and Behavioral Research: A Primer. *Front Public Health*, 6, 149. https://doi.org/10.3389/fpubh.2018.00149

Burgsteiner, H., Kandlhofer, M., and Steinbauer, G. (2016). IRobot: Teaching the Basics of Artificial Intelligence in High Schools. *Proceedings of the AAAI Conference on Artificial Intelligence*, [e-journal] 30(1). https://doi.org/10.1609/aaai.v30i1.9864

Celik, I. (2023a). Exploring the Determinants of Artificial Intelligence (AI) Literacy: Digital Divide, Computational Thinking, Cognitive Absorption. *Telematics and Informatics, [e-journal] 83, pp.102026. https://doi.org/10.1016/j.tele.2023.102026*

Celik, I. (2023b). Towards Intelligent-TPACK: An empirical study on teachers' professional knowledge to ethically integrate artificial intelligence (AI)-based tools into education. *Computers in Human Behavior*, [e-journal] 138, pp.107468. https://doi.org/10.1016/j.chb.2022.107468

Chan, C. K. Y. (2023). A comprehensive AI policy education framework for university teaching and learning. *International Journal of Educational Technology in Higher Education*, [e-journal] 20(1). https://doi.org/10.1186/s41239-023-00408-3

Chaudhry, M. A., and Kazim, E. (2022). Artificial Intelligence in Education (AIEd): a high-level academic and industry note 2021. *AI and Ethics*, [e-journal] 2(1), pp.157-165. https://doi.org/10.1007/s43681-021-00074-z

Chen, J. J., and Lin, J. C. (2023). Artificial intelligence as a double-edged sword: Wielding the POWER principles to maximize its positive effects and minimize its negative effects. *Contemporary Issues in Early Childhood*. [online] Available at: https://doi.org/10.1177/14639491231169813 [Accessed 27 November 2023].

Chiang, C. W., and Yin, M. (2022). Exploring the Effects of Machine Learning Literacy Interventions on Laypeople's Reliance on Machine Learning Models. *International Conference on Intelligent User Interfaces*, Proceedings IUI,

Dai, Y., Chai, C. S., Lin, P. Y., Jong, M. S. Y., Guo, Y., and Qin, J. (2020). Promoting students'well-being by developing their readiness for the artificial intelligence age. *Sustainability (Switzerland)*, [e-journal] 12(16). https://doi.org/10.3390/su12166597

Davy Tsz Kit, N. G., Luo, W., Chan, H. M. Y., and Chu, S. K. W. (2022). Using digital story writing as a pedagogy to develop AI literacy among primary students. *Computers and Education: Artificial Intelligence*, [e-journal] 3. https://doi.org/10.1016/j.caeai.2022.100054

DeVellis, R. F. (2012). *Scale Development: Theory and Applications*. SAGE Publications.

Du, H., Sun, Y., Jiang, H., Islam, A. Y. M. A., and Gu, X. (2024). Exploring the effects of AI literacy in teacher learning: an empirical study. *Humanities and Social Sciences Communications*, [e-journal] 11(1). https://doi.org/10.1057/s41599-024-03101-6

Eguchi, A., Okada, H., and Muto, Y. (2021). Contextualizing AI Education for K-12 Students to Enhance Their Learning of AI Literacy Through Culturally Responsive Approaches. *KI - Kunstliche Intelligenz*, [e-journal] 35(2), pp.153-161. https://doi.org/10.1007/s13218-021-00737-3

Fan, X., Thompson, B., and Wang, L. (1999). Effects of sample size, estimation methods, and model specification on structural equation modeling fit indexes. Structural equation modeling: a multidisciplinary journal, 6(1), 56-83.

Fornell, C., and Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, [e-journal] 18(1), pp.39-50. https://doi.org/10.2307/3151312

Ghallab, M. (2019). Responsible AI: requirements and challenges. *AI Perspectives*, [e-journal] 1(1), pp.3. https://doi.org/10.1186/s42467-019-0003-z

Hair, J. F. (1998). *Multivariate Data Analysis* (Vol. 5). Upper Saddle River, NJ: Prentice hall.

Hair, J. F., Black, W. C., Babin, B. J., and Anderson, R. E. (2018). *Multivariate data analysis* (8th ed.). Cengage.

Hooper, D., Coughlan, J., and Mullen, M. (2007). Structural Equation Modeling: Guidelines for Determining Model Fit. *The Electronic Journal of Business Research Methods*, pp.6.

Hwang, G.-J., Xie, H., Wah, B. W., and Gašević, D. (2020). Vision, challenges, roles and research issues of Artificial Intelligence in Education. *Computers and Education: Artificial Intelligence*, [e-journal] 1, pp.100001. https://doi.org/10.1016/j.caeai.2020.100001

Jang, J., Jeon, J., and Jung, S. K. (2022). Development of STEM-Based AI Education Program for Sustainable Improvement of Elementary Learners. *Sustainability (Switzerland)*, [e-journal] 14(22). https://doi.org/10.3390/su142215178

Jöreskog, K. G., and Sörbom, D. (1986). LISREL VI: Analysis of Linear Structural Relationships by Maximum Likelihood, Instrumental Variables, and Least Squares Methods. Scientific Software.

Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., and Huber, P. (2016). Artificial intelligence and computer science in education: From kindergarten to university. *2016 IEEE Frontiers in Education Conference (FIE)*,

Kanont, K., Pingmuang, P., Simasathien, T., Wisnuwong, S., Wiwatsiripong, B., Poonpirome, K., Songkram, N., and Khlaisang, J. (2024). Generative-AI, a Learning Assistant? Factors Influencing Higher-Ed Students' Technology Acceptance. *Electronic Journal of e-Learning*, [e-journal] 22(6), pp.18-33. https://doi.org/10.34190/ejel.22.6.3196

Khammarnia, M., Golestani, Z. S., Ranjbar, A. A., Peyvand, M., Khorram, A., and Setoodehzadeh, F. (2022). Relationship of Information Literacy and Professional Ethics with Career Development. *Shiraz E Medical Journal*, [e-journal] 23(9). https://doi.org/10.5812/semj-111166

Khlaisang, J., and Koraneekij, P. (2019). Open online assessment management system platform and instrument to enhance the information, media, and ICT literacy skills of 21st century learners. *International Journal of Emerging Technologies in Learning*, [e-journal] 14(7), pp.111-127. https://doi.org/10.3991/ijet.v14i07.9953

Kim, K., and Kwon, K. (2023). Exploring the AI competencies of elementary school teachers in South Korea. *Computers and Education: Artificial Intelligence*, [e-journal] 4. https://doi.org/10.1016/j.caeai.2023.100137

Kim, S., Jang, Y., Choi, S., Kim, W., Jung, H., Kim, S., and Kim, H. (2021). Analyzing Teacher Competency with TPACK for K-12 AI Education. *KI - Kunstliche Intelligenz*, [e-journal] 35(2), pp.139-151. https://doi.org/10.1007/s13218-021-00731-9

Kim, S., Jang, Y., Choi, S., Kim, W., Jung, H., Kim, S., and Kim, H. (2022). Correction to: Analyzing Teacher Competency with TPACK for K-12 AI Education. *KI - Kunstliche Intelligenz*, [e-journal] 36(2), pp.187-187. https://doi.org/10.1007/s13218-022-00770-w

Kohnke, L., Zou, D., Ou, A. W., and Gu, M. M. (2025). Preparing future educators for AI-enhanced classrooms: Insights into AI literacy and integration. *Computers and Education: Artificial Intelligence*, [e-journal] 8, pp.100398. https://doi.org/10.1016/j.caeai.2025.100398

Kong, S.-C., Man-Yin Cheung, W., and Zhang, G. (2021). Evaluation of an artificial intelligence literacy course for university students with diverse study backgrounds. *Computers and Education: Artificial Intelligence*, [e-journal] 2, pp.100026. https://doi.org/10.1016/j.caeai.2021.100026

Kong, S. C., Cheung, W. M. Y., and Tsang, O. (2022). Evaluating an artificial intelligence literacy programme for empowering and developing concepts, literacy and ethical awareness in senior secondary students. *Education and Information Technologies*. https://doi.org/10.1007/s10639-022-11408-7

Kong, S. C., Man-Yin Cheung, W. M. Y., and Tsang, O. (2023). Evaluating an artificial intelligence literacy programme for empowering and developing concepts, literacy and ethical awareness in senior secondary students. *Education and Information Technologies*, [e-journal] 28(4), pp.4703-4724. https://doi.org/10.1007/s10639-022-11408-7

Laupichler, M. C., Aster, A., Haverkamp, N., and Raupach, T. (2023). Development of the "Scale for the assessment of non-experts' AI literacy" – An exploratory factor analysis. *Computers in Human Behavior Reports*, [e-journal] 12, pp.100338. https://doi.org/10.1016/j.chbr.2023.100338

Laupichler, M. C., Hadizadeh, D. R., Wintergerst, M. W. M., von der Emde, L., Paech, D., Dick, E. A., and Raupach, T. (2022). Effect of a flipped classroom course to foster medical students' AI literacy with a focus on medical imaging: a single group pre-and post-test study. *BMC Medical Education*, [e-journal] 22(1). https://doi.org/10.1186/s12909-022-03866-x

Lee, I., Ali, S., Zhang, H., Dipaola, D., and Breazeal, C. (2021). Developing Middle School Students' AI Literacy. *SIGCSE 2021 - Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*,

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 22 140, 55-55.

Long, D., Blunt, T., and Magerko, B. (2021). Co-Designing AI Literacy Exhibits for Informal Learning Spaces. *Proceedings of the ACM on Human-Computer Interaction*, 5(CSCW2). https://doi.org/10.1145/3476034

Luo, T., Muljana, P. S., Ren, X., and Young, D. (2024). Exploring instructional designers' utilization and perspectives on generative AI tools: A mixed methods study. *Educational Technology Research and Development*. https://doi.org/10.1007/s11423-024-10437-y

MacCallum, R. C., Browne, M. W., and Sugawara, H. M. (1996). Power analysis and determination of sample size for covariance structure modeling. Psychological methods, [e-journal] 1(2), pp.130.

Markauskaite, L., Marrone, R., Poquet, O., Knight, S., Martinez-Maldonado, R., Howard, S., Tondeur, J., De Laat, M., Buckingham Shum, S., Gašević, D., and Siemens, G. (2022). Rethinking the entwinement between artificial intelligence and human learning: What capabilities do learners need for a world with AI? *Computers and Education: Artificial Intelligence*, [e-journal] 3, pp. 100056. https://doi.org/10.1016/j.caeai.2022.100056

Ministry of Higher Education, Science, Research and Innovation. (2023). *Annual Report 2023 National AI Action Plan for Thailand's Development (2022 - 2027)*. The National Digital Economy and Society Commission. [online] Available at: <https://ai.in.th/about-ai-thailand/> [Accessed 27 November 2023].

Ng, D. T. K., Leung, J. K. L., Chu, K. W. S., and Qiao, M. S. (2021a). AI Literacy: Definition, Teaching, Evaluation and Ethical Issues. *Proceedings of the Association for Information Science and Technology*, [e-journal] 58(1), pp.504-509. https://doi.org/10.1002/pra2.487

Ng, D. T. K., Leung, J. K. L., Chu, S. K. W., and Qiao, M. S. (2021b). Conceptualizing AI literacy: An exploratory review. *Computers and Education: Artificial Intelligence*, [e-journal] 2, pp.100041. https://doi.org/10.1016/j.caeai.2021.100041

Ng, D. T. K., Leung, J. K. L., Su, J., Ng, R. C. W., and Chu, S. K. W. (2023a). Teachers' AI digital competencies and twenty-first century skills in the post-pandemic world. *Educational Technology Research and Development*, [e-journal] 71(1), pp.137-161. https://doi.org/10.1007/s11423-023-10203-6

Ng, D. T. K., Wu, W., Leung, J. K. L., Chiu, T. K. F., and Chu, S. K. W. (2023b). Design and validation of the AI literacy questionnaire: The affective, behavioural, cognitive and ethical approach. *British Journal of Educational Technology*. https://doi.org/10.1111/bjet.13411

Oster, N., Henriksen, D., and Mishra, P. (2024). ChatGPT for Teachers: Insights from Online Discussions. TechTrends, [e-journal] 68(4), pp.640-646. https://doi.org/10.1007/s11528-024-00992-9

Pinski, M., and Benlian, A. (2023). AI Literacy - Towards Measuring Human Competency in Artificial Intelligence. *Proceedings of the 56th Hawaii International Conference on System Sciences, Maui*, USA: IEEE Computer Society Press.

Preston, C., and Colman, A. (2000). Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences. *Acta Psychologica*, 104(1), 1–15. https://doi.org/10.1016/S0001-6918(99)00050-5

Richards, D., and Dignum, V. (2019). Supporting and challenging learners through pedagogical agents: Addressing ethical issues through designing for values. *British Journal of Educational Technology*, [e-journal] 50(6), pp.2885-2901. https://doi.org/10.1111/bjet.12863

Seo, K., Tang, J., Roll, I., Fels, S., and Yoon, D. (2021). The impact of artificial intelligence on learner–instructor interaction in online learning. International Journal of Educational Technology in Higher Education, [e-journal] 18(1), pp.54. https://doi.org/10.1186/s41239-021-00292-9

Soper, D. (2022). A-priori Sample Size Calculator for Structural Equation Models [Software]. Available at: <https://www.danielsoper.com/statcalc>

Steinbauer, G., Kandlhofer, M., Chklovski, T., Heintz, F., and Koenig, S. (2021). A Differentiated Discussion About AI Education K-12. KI - Kunstliche Intelligenz, [e-journal] 35(2), pp.131-137. https://doi.org/10.1007/s13218-021-00724-8

Sukkeewan, P., Songkram, N., and Nasongkhla, J. (2024). Investigating Students' Behavioral Intentions towards a Smart Learning Platform Based on Machine Learning: A User Acceptance and Experience Perspective. *International Journal of Information and Education Technology*, [e-journal] 14(2), pp.260-270. https://doi.org/10.18178/ijiet.2024.14.2.2047

Tabachnick, B. G., and Fidell, L. S. (2013). *Using Multivariate Statistics* (6 ed.). Pearson Education Limited.

The jamovi project. (2024). jamovi. In (Version 2.5) [Computer Software]. Available at: <https://www.jamovi.org>

U.S. Department of Education, Office of Educational Technology. (2023). *Artificial Intelligence and Future of Teaching and Learning: Insights and Recommendation*. Washington, DC

UNESCO. (2023). *The challenges and opportunities of Artificial Intelligence in education*. [e-book] Available at: <https://www.unesco.org/en/articles/challenges-and-opportunities-artificial-intelligence-education>

UNESCO. (2024). *AI competency framework for teachers*. [e-book] Available at: <https://unesdoc.unesco.org/ark:/48223/pf0000391104.locale=en>

Vagias, W. M. (2006). Likert-type scale response anchors. Clemson International Institute for Tourism & Research Development, Department of Parks, Recreation and Tourism Management. Clemson University. [e-book] Available at: <http://media.clemson.edu/cbshs/prtm/research/resources-for-research-page-2/Vagias-Likert-Type-Scale-Response-Anchors.pdf>

Vuorikari, R., Kluzer, S., and Punie, Y. (2022). DigComp 2.2*, The Digital Competence framework for citizens – With new examples of knowledge, skills and attitudes*. Publications Office of the European Union. [e-book] Available at: <https://doi.org/doi/10.2760/115376>

Wang, B., Rau, P. L. P., and Yuan, T. (2022). Measuring user competence in using artificial intelligence: validity and reliability of artificial intelligence literacy scale. *Behaviour and Information Technology*. https://doi.org/10.1080/0144929X.2022.2072768

Weston, D. (2023). Understanding AI for School: tips for school leaders. [e-book] Available at: <https://tdtrust.org/wp-content/uploads/2023/09/AI-for-UK-School-Leaders.pdf>

Williams, R., Ali, S., Devasia, N., DiPaola, D., Hong, J., Kaputsos, S. P., Jordan, B., and Breazeal, C. (2022). AI + Ethics Curricula for Middle School Youth: Lessons Learned from Three Project-Based Curricula. *International Journal of Artificial Intelligence in Education*. https://doi.org/10.1007/s40593-022-00298-y

Wilson, M., Scalise, K., and Gochyyev, P. (2015). Rethinking ICT literacy: From computer skills to social network settings. Thinking Skills and Creativity, [e-journal]18, pp.65-80. https://doi.org/10.1016/j.tsc.2015.05.001

Wilton, L., Ip, S., Sharma, M., and Fan, F. (2022). Where Is the AI? AI Literacy for Educators. In M. M. Rodrigo, N. Matsuda, A. I. Cristea, & V. Dimitrova (Eds.), *23rd International Conference on Artificial Intelligence in Education, AIED 2022* (Vol. 13356 LNCS, pp. 180-188): Springer Science and Business Media Deutschland GmbH.

Wong, G. K. W., Ma, X., Dillenbourg, P., and Huan, J. (2020). Broadening artificial intelligence education in K-12: where to start? ACM Inroads, [e-journal]11(1), pp.20–29. https://doi.org/10.1145/3381884

Yetişensoy, O., and Rapoport, A. (2023). Artificial intelligence literacy teaching in social studies education. *Journal of Pedagogical Research*, [e-journal] 7(3), pp.100-110. https://doi.org/10.33902/JPR.202320866

Zhao, L., Wu, X., and Luo, H. (2022). Developing AI Literacy for Primary and Middle School Teachers in China: Based on a Structural Equation Modeling Analysis. *Sustainability (Switzerland)*, [e-journal] 14(21), pp.14549. https://doi.org/10.3390/su142114549

Appendix

These revised components and items of AI literacy for pre-service teachers in the following table were translated from Thai to English.

Items
AI Recognition (8 items):
1. I believe that using AI in services or products enhances my study and works more efficiently.
2. I think the current AI stimulates learners to adapt their methods of learning various subjects.
3. I believe that AI technology will become a part of future teaching and learning management.
4. I can provide reasons for the current use of AI in education.
5. I can clarify the reasons and necessity for integrating AI as a tool in teaching and learning management.
6. I can explain the benefits of AI that should be considered for their impact on teaching and learning management.
7. I can state the limitations and conditions of the use of various forms of AI.
8. I thoroughly check the results or information developed with AI before publishing or utilizing them.
AI Fundamental Comprehension (12 items):
1. I can explain the basic functioning of AI (e.g., social media and e-commerce platforms) in digital services and applications.
2. I can describe the processing work of Gen-AI from the information students read or listen to generated by Gen-AI processing.
3. I can specify the working characteristics of each type of AI (e.g., text-based, image-based, video-based).
4. I can point out the differences between the content generated by AI and the content created by humans.
5. I can classify the information I have read or heard according to each AI working type.
6. I can identify guidelines for selecting AI usage according to AI capability levels (e.g., specialized Gen-AI and multimodal Gen-AI).
7. I can explain why I chose particular AI services or tools as the assistance for designing a course's learning and teaching assistants.
8. I can identify observation points to distinguish the content parts resulting from AI usage.
9. I can clearly explain the reasons to confirm that the perceived content comes from AI.
10. I scrutinize the appropriateness before using AI in the learning design.
11. I can share knowledge about AI applications that can be used in educational contexts.
12. I explain the benefits and limitations of using AI to support usage and learning management.

Items
AI Pedagogy (7 items):
1. I can design learning activities including AI as a teaching aid.
2. I can organize and evaluate learning activities that use AI to promote learners' knowledge and skills.
3. I can demonstrate the steps of using AI to students, teachers, and fellow students.
4. I can show how to use AI to support learners' learning in my subjects.
5. I demonstrate AI usage while incorporating cautions, usage options, and all possible outcomes from its use.
6. I can design an AI usage agreement framework for learners in my course.
7. I can explain the reasons for setting AI usage boundaries to the learners.
AI Ethical Use (12 items):
1. I consider the ethical aspects of AI when deciding to use information that it has processed.
2. I am aware of the information processed by AI may infringe copyright.
3. I thoroughly account for the use of AI-generated information to ensure that it aligns with the institution's rules and agreements.
4. I filter and check data characteristics before inputting them into the AI for processing to ensure that personal and institutional data are secure.
5. I recognize that AI usage data in AI services will be used under the provider's conditions.
6. I am aware of the consequences of unethical AI usage and intellectual property violations.
7. I use AI considering the educational institution's regulations, requirements, or AI usage frameworks.
8. I inform stakeholders in professional teaching practices when using AI-generated data to design learning, lesson plans, learning activities, or portfolios.
9. I guide, supervise, and monitor learners' and others' AI usage to ensure compliance with rules, frameworks, and usage conditions.
10. I consider the necessity of using AI before doing so.
11. I try to think and search for answers thoroughly to solve problems or find information before using AI to help address those issues.
12. I use AI critically, applying my skills and independent thinking.

