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Developing and Validating an AI Literacy Instrument for Elementary School Students: A Psychometric Study Using the ADDIE Framework

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Abstract

Artificial intelligence (AI) literacy has emerged as a critical competency in elementary education as learners increasingly engage with AI-mediated and technology-rich learning environments. This study developed and validated a multidimensional AI literacy instrument for elementary school students using a research and development approach grounded in the ADDIE framework and informed by AI literacy, constructivist learning, and digital citizenship theories. The instrument comprised five dimensions: AI recognition, conceptual understanding, functional application, evaluation and creation, and AI ethics. Content validation by four experts demonstrated strong theoretical relevance across all dimensions. Empirical testing involving 250 Indonesian elementary school students examined the instrument's psychometric properties. Exploratory factor analysis supported a five-factor structure with acceptable factor loadings and sampling adequacy (KMO > .80; Bartlett's test, $p < .001$), explaining a substantial proportion of total variance. Reliability analysis indicated satisfactory internal consistency across retained subscales (Cronbach's $\alpha > .70$), although conceptual understanding required minor item revision. Descriptive findings revealed stronger competencies in ethical AI use and functional application than in conceptual understanding of AI processes. The study contributes a psychometrically grounded and developmentally appropriate instrument supporting AI literacy assessment, curriculum innovation, instructional evaluation, and responsible AI integration within primary education contexts for early twenty-first-century educational transformation.

Keywords: AI literacy, instrument development, psychometric validation, elementary education, educational technology, ADDIE framework

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1. Introduction

1.1. Introduction to the Problem

Artificial intelligence (AI) is increasingly transforming educational environments through adaptive learning systems, intelligent tutoring technologies, automated feedback systems, and generative AI applications. The rapid advancement of digital technology has significantly influenced how individuals access information, communicate, solve problems, and participate in learning activities. Educational environments are no longer confined to traditional instructional approaches but are evolving into dynamic and AI-supported learning ecosystems that require students to possess not only operational digital skills but also deeper understanding of emerging technologies such as AI (Yue, Jong, Dai, & Lau, 2025). The concept of literacy has expanded beyond traditional reading and writing toward digital, information, technological, and AI literacy competencies required in contemporary society (Ningsih & Sayekti, 2023; Chung et al., 2025).

The growing integration of AI into education has intensified 21st-century learning demands. Students are increasingly expected to demonstrate critical thinking, creativity, problem-solving, and adaptability within evolving digital environments. These competencies are closely associated with the ability to understand and utilise AI technologies responsibly and critically. Without sufficient AI literacy, students may become passive consumers of AI-generated information rather than reflective and analytical users of technology. Furthermore, the increasing prevalence of AI-generated content raises important concerns regarding information accuracy, algorithmic bias, ethical use, and digital responsibility. Students therefore require competencies that enable them to critically evaluate AI-generated outputs and make informed decisions within digital environments (Siregar, Fauzan, Yerizon, & Syafriandi, 2025). These developments reinforce the need for educational systems to integrate AI literacy into formal learning processes to prepare learners for the challenges of increasingly AI-mediated environments (Yeter, Yang, & Sturgess, 2024).

1.2. AI Literacy in Elementary Education

Within this context, elementary education represents a critical stage for the development of foundational AI literacy competencies. At the elementary level, students begin developing cognitive abilities such as reasoning, analysis, problem-solving, and pattern recognition, which are essential for understanding how AI systems function. Early exposure to AI literacy may foster positive engagement with technology while simultaneously supporting curiosity, critical awareness, and responsible digital behaviour. Introducing AI literacy during early education may also help prevent misconceptions regarding AI capabilities and limitations while encouraging balanced and developmentally appropriate understanding of intelligent technologies (Kempa et al., 2024; Hong & Kim, 2025). Moreover, AI literacy education at the primary level supports the development of ethical awareness concerning privacy, data security, academic integrity, and responsible technology use. These ethical dimensions become increasingly important as students interact more frequently with AI-assisted learning systems, generative AI tools, and AI-based instructional media integrated into classroom learning (Sabatini et al., 2023; Hidayati, 2023).

1.3. Current Research on AI Literacy in Education

Recent educational technology research has increasingly examined the role of AI in learning environments, including AI-enhanced inquiry learning, AI-supported informal learning, and AI-mediated student interaction processes. A recent systematic literature review further demonstrates that artificial intelligence has become an integral component of educational innovation, supporting personalized learning, intelligent tutoring, learning analytics, assessment, and adaptive instructional systems across educational contexts (Wang et al., 2024). Existing studies indicate that AI technologies may support personalised learning, cognitive engagement, and AI awareness through instructional activities and introductory AI programs implemented in schools (Amalia et al., 2025; Hasdyna et al., 2025) highlighted that AI integration in education provides opportunities for adaptive and interactive learning through technologies such as chatbots and virtual tutors. Similarly, Maleni et al. (2025) emphasised that AI literacy constitutes an essential competency for preparing students to engage with technological advancement in the 21st century. However, these studies primarily focus on conceptual discussions, technological opportunities, or ethical implications of AI integration rather than empirical measurement of elementary students' AI literacy competencies.

1.4. Research Gap

Although several AI literacy frameworks have been proposed, empirical instruments specifically designed for elementary school students remain limited. Existing studies rarely examine elementary students' AI literacy across measurable multidimensional constructs such as recognising AI, understanding AI concepts, applying AI functionally, evaluating AI-generated outputs, and engaging ethically with AI systems. Furthermore, limited psychometric evidence exists regarding the validity and reliability of AI literacy instruments appropriate for primary education contexts. This gap is significant because elementary school students increasingly interact with AI technologies in everyday digital environments despite limited understanding of how these systems function and influence learning processes.

1.5. Purpose of the Study

To address this gap, this study aims to develop and validate an AI literacy instrument for elementary school students using a research and development approach based on the ADDIE framework. The instrument was constructed across five dimensions: recognising AI, understanding AI, function/use/apply AI, evaluate and create AI, and AI ethics. The study further examines the content validity, empirical validity, reliability, and dimensional structure of the instrument using responses from 250 elementary school students in Indonesia. This study contributes an empirically grounded instrument that may support AI literacy assessment, curriculum development, instructional evaluation, and future educational technology research in elementary education contexts. More importantly, the study extends current AI literacy scholarship by operationalising developmentally appropriate multidimensional AI literacy constructs for elementary education within emerging AI-mediated learning environments.

2. LITERATURE REVIEW

2.1. Artificial Intelligence Literacy in Education

The rapid expansion of artificial intelligence (AI) technologies across educational environments has intensified the need for AI literacy as an essential 21st-century competency. AI-supported systems such as intelligent tutoring platforms, adaptive learning technologies, automated feedback systems, learning analytics, and generative AI applications increasingly shape how learners access information, construct knowledge, and participate in educational activities (Yue et al., 2025; Yim & Su, 2025). Consequently, educational institutions are expected not only to integrate AI technologies into instructional processes but also to prepare learners to critically understand, evaluate, and responsibly engage with AI-mediated environments (Sabatini et al., 2023).

AI literacy is commonly defined as a set of competencies enabling individuals to understand AI concepts, critically evaluate AI systems, communicate effectively with intelligent technologies, and apply AI tools appropriately within learning and problem-solving contexts (Long & Magerko, 2020). Rather than representing purely operational digital skills, AI literacy encompasses conceptual understanding, critical evaluation, ethical awareness, and reflective engagement with intelligent systems (Su et al., 2023). Ng et al. (2024) further argue that AI literacy includes learners' abilities to formulate prompts, interpret AI-generated outputs, evaluate information reliability, and integrate AI-supported information into decision-making processes. As generative AI technologies become increasingly accessible within educational contexts, these competencies are becoming progressively important for younger learners (Hong & Kim, 2025).

Within K–12 education, AI literacy has gained increasing scholarly attention because students regularly interact with AI-supported applications despite limited understanding of how such systems operate (Touretzky et al., 2019). Early exposure to AI concepts may support the gradual development of foundational technological understanding that can be expanded across later educational stages (Williams et al., 2019). Elementary learners can engage with simplified AI concepts such as automation, recommendation systems, pattern recognition, and generative content creation through developmentally appropriate instructional approaches (Kong et al., 2021). Research additionally suggests that early AI literacy development may foster technological confidence, critical awareness, digital responsibility, and reflective technology use while reducing passive dependence on AI-generated information (Yang et al., 2026).

Recent educational technology studies further emphasize that AI-supported learning environments increasingly require learners to engage in higher-order thinking, inquiry, metacognitive monitoring, and evaluative reasoning (Yeter et al., 2024). AI-enhanced inquiry learning environments often require students to critically evaluate information reliability, identify algorithmic bias, and assess AI-generated content using reflective judgment and analytical thinking (Sabatini et al., 2023). Consequently, AI literacy is increasingly viewed as an essential educational competency supporting critical thinking, ethical awareness, digital participation, and responsible engagement within AI-mediated learning environments (Chung et al., 2025).

2.1. Frameworks and Dimensions of AI Literacy

The growing importance of AI literacy has encouraged scholars to propose multidimensional frameworks structuring the competencies necessary for effective engagement with intelligent technologies. One influential framework proposed by Touretzky et al. (2019) identifies five "big ideas" for K–12 AI education: Perception, Representation and Reasoning, Learning, Natural Interaction, and Societal Impact. These foundational concepts were subsequently expanded into a broader AI literacy framework that emphasizes developmentally appropriate learning progression and curriculum integration across K–12 education (Touretzky et al., 2022). Collectively, these frameworks emphasize that AI literacy extends beyond technical operation toward conceptual understanding of how AI systems perceive information, learn from data, interact with users, and influence society.

Similarly, Ng et al. (2024) conceptualized AI literacy through four dimensions: Know and Understand AI, Use and Apply AI, Evaluate and Create AI, and AI Ethics. These dimensions reflect progression from foundational conceptual understanding toward higher-order analytical and ethical competencies. The “Know and Understand AI” dimension focuses on comprehension of AI principles and operational mechanisms, whereas the “Use and Apply AI” dimension emphasizes practical interaction with AI-supported technologies. The “Evaluate and Create AI” dimension captures critical evaluation and creative engagement with AI-generated outputs, while the “AI Ethics” dimension addresses responsible technology use, including fairness, privacy, accountability, and ethical awareness.

Recent educational technology research reinforces the importance of these multidimensional perspectives by highlighting how AI-mediated learning increasingly requires learners to engage in inquiry, reflection, creativity, and evaluative thinking (Yim & Su, 2025). Constructivist-oriented AI studies further suggest that meaningful AI integration depends on learners functioning as active participants capable of questioning, evaluating, revising, and reflecting on AI-generated information rather than merely consuming technological outputs (Su et al., 2023; Kong et al., 2021). Other recent studies additionally emphasize that AI literacy frameworks should integrate cognitive, technical, ethical, and social dimensions simultaneously because AI technologies increasingly influence decision-making, communication, and digital participation across educational settings (Yeter et al., 2024; Yang et al., 2026).

Grounded in these perspectives, the present study operationalizes AI literacy across five dimensions: Recognizing AI, Understanding AI, Function/Use Apply AI, Evaluate and Create AI, and AI Ethics. These dimensions align closely with established AI literacy scholarship while reflecting competencies developmentally appropriate for elementary education contexts. Aligning the instrument with established theoretical perspectives strengthens conceptual validity and supports the development of a multidimensional AI literacy assessment appropriate for young learners.

2.2. Challenges in Assessing AI Literacy in Elementary Schools

Despite increasing scholarly attention toward AI literacy education, assessing AI literacy among elementary school students remains methodologically challenging. One major difficulty concerns the abstract nature of AI concepts such as algorithms, machine learning, automation, and generative systems. Young learners often struggle to understand invisible computational processes because these concepts require levels of abstraction that are still developing during childhood (Williams et al., 2019). Consequently, AI literacy assessment instruments must translate complex technological concepts into developmentally appropriate language and contexts suitable for elementary learners (Hong & Kim, 2025).

Another challenge involves the limited availability of empirically validated AI literacy instruments specifically designed for elementary education contexts. Existing AI literacy studies frequently focus on secondary schools, higher education, teacher readiness, or conceptual frameworks rather than psychometrically validated instruments appropriate for younger learners. Kong et al. (2021) further highlighted that many AI education studies continue to rely heavily on qualitative approaches such as interviews, observations, and exploratory reflections rather than multidimensional quantitative measurement instruments. Although qualitative approaches provide valuable insights into learner experiences, they often lack the scalability and comparability necessary for broader educational assessment.

The multidimensional nature of AI literacy also complicates instrument development because assessment frameworks must simultaneously capture conceptual understanding, practical application, evaluative reasoning, creativity, and ethical awareness (Long & Magerko, 2020). Research indicates that students interacting with AI-supported environments frequently experience difficulty critically evaluating AI-generated information, identifying misinformation, and recognizing potential algorithmic bias without appropriate scaffolding and reflective guidance (Sabatini et al., 2023; Yue et al., 2025). These findings suggest that AI literacy assessment should extend beyond operational technology use toward broader evaluative and ethical competencies.

Despite increasing discussions concerning AI literacy integration within primary education, relatively limited empirical studies have developed psychometrically validated instruments specifically designed for elementary school students. Existing studies predominantly emphasize conceptual discussions, higher education contexts, teacher perceptions, or AI-supported instructional environments rather than multidimensional assessment of young learners' AI literacy competencies (Yim & Su, 2025). Furthermore, limited evidence exists regarding the validity, reliability, and dimensional structure of AI literacy instruments appropriate for primary education settings.

Addressing these gaps, the present study develops and validates a multidimensional AI literacy instrument for elementary school students grounded in established AI literacy frameworks proposed by Touretzky et al. (2019) and Ng et al. (2021). The instrument operationalizes five dimensions: Recognizing AI, Understanding AI, Function/Use Apply AI, Evaluate and Create AI, and AI Ethics. Using a research and development approach based on the ADDIE framework, the study further examines the instrument's validity, reliability, and dimensional structure using responses from 250 elementary school students in Indonesia. By providing a psychometrically grounded and developmentally appropriate AI literacy assessment instrument, the study contributes to emerging educational technology scholarship concerning AI literacy development within primary education contexts.

2.3. Thoeretical Framework of the Study

This study is informed by three complementary perspectives: AI literacy theory, constructivist learning theory, and digital citizenship theory. These perspectives collectively explain how elementary school students develop conceptual understanding, practical engagement, evaluative judgment, and ethical awareness in interacting with artificial intelligence technologies.

The study conceptualizes AI literacy as a multidimensional construct consisting of recognizing AI, understanding AI concepts, applying AI tools, evaluating and creating AI-assisted outputs, and demonstrating ethical AI use. These dimensions reflect competencies necessary for meaningful participation within AI-enhanced learning environments.

AI literacy theory explains that learners require more than operational digital skills to engage effectively with intelligent technologies. AI literacy involves conceptual understanding of AI systems, critical interpretation of AI-generated outputs, responsible use of intelligent technologies, and reflective awareness of their societal implications (Long & Magerko, 2020; Su et al., 2023). Within elementary education, this perspective supports the development of foundational competencies enabling students to interact critically and responsibly with AI-supported learning environments.

Constructivist learning theory emphasizes that knowledge is actively constructed through interaction, exploration, and reflective learning experiences. Students develop understanding by engaging with authentic learning tasks, connecting new experiences with prior knowledge, and critically evaluating information (Piaget, 1972; Vygotsky, 1978). In AI-supported educational contexts, constructivist perspectives support the inclusion of application, evaluation, and creative engagement dimensions because meaningful AI literacy develops through active interaction rather than passive technology consumption (Kong et al., 2021; Williams et al., 2019).

Digital citizenship theory provides an ethical perspective for understanding responsible participation within digital environments. The theory emphasizes ethical technology use, information evaluation, privacy awareness, respectful communication, and responsible digital participation (Ribble, 2015; Jones & Mitchell, 2016). Within this study, AI ethics represents the responsible dimension of AI literacy, ensuring that students develop awareness of safe, ethical, and constructive AI use in educational contexts (Yeter et al., 2024).

Collectively, these perspectives position AI literacy as an interactional and developmental construct emerging through learners' active engagement, reflective evaluation, and ethical participation within AI-mediated learning environments. The framework further explains how conceptual understanding, practical application, evaluative thinking, and ethical awareness interact to shape elementary students' AI literacy development. In this study, these theoretical perspectives guided the operationalization of the five AI literacy dimensions and informed the development of instrument indicators, item construction, and psychometric evaluation procedures.

Based on the identified gaps in AI literacy assessment among elementary school students, this study addresses the following research questions:

1. How can a multidimensional AI literacy instrument for elementary school students be developed using the ADDIE framework?

2. To what extent does the developed AI literacy instrument demonstrate acceptable psychometric properties in terms of content validity, construct validity, and reliability?

3. What factor structure emerges from the exploratory factor analysis of the developed AI literacy instrument?

4. What are the levels of elementary school students' AI literacy across the dimensions of AI recognition, conceptual understanding, functional application, evaluation and creation, and AI ethics?

3. Research Methodology

This study employed a research and development (R&D) design to develop and validate an artificial intelligence (AI) literacy instrument for elementary school students. The study adopted the ADDIE framework consisting of five interconnected phases: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because it provides a systematic and iterative framework for educational instrument development, enabling researchers to conduct needs analysis, develop instrument specifications, validate measurement items, implement pilot testing, and refine the instrument through evaluation procedures (Arini et al., 2020; Krismony et al., 2020; Hidayat & Nizar, 2021; Firda, 2023). The study was conducted during the 2025/2026 academic year at SD Negeri 1 Sinunukan, Mandailing Natal Regency, North Sumatra, Indonesia, involving 250 elementary school students from Grades III and IV.

3.1. Research Design

The development process focused on constructing a multidimensional AI literacy instrument appropriate for elementary education contexts. The instrument was designed to measure five dimensions of AI literacy: Recognizing AI, Understanding AI, Function/Use Apply AI, Evaluate and Create AI, and AI Ethics. The development procedures were informed by established AI literacy frameworks proposed by Touretzky et al. (2019) and Ng et al. (2021), which conceptualize AI literacy as an integration of conceptual understanding, practical engagement, evaluative reasoning, creativity, and ethical awareness.

3.2. Participants and Sampling

The participants consisted of 250 elementary school students enrolled in Grades III and IV. Participants were selected using purposive sampling because the study specifically targeted learners with prior exposure to digital technologies and AI-supported applications within educational or everyday contexts. Purposive sampling is appropriate in instrument-development research when participant selection is aligned with construct relevance and contextual experience (Creswell & Creswell, 2018; Etikan et al., 2016).

The selected grade levels represented developmentally appropriate stages for examining foundational AI literacy competencies involving recognition, conceptual understanding, functional application, evaluative judgment, and ethical AI engagement. In addition, four experts specializing in educational technology, elementary education, educational measurement, and digital learning participated in the content validation process.

3.3. Instrument Development Procedures

The instrument was developed across five AI literacy dimensions: Recognizing AI, Understanding AI, Function/Use Apply AI, Evaluate and Create AI, and AI Ethics The development procedures also followed established practices in elementary educational instrument development emphasizing systematic indicator construction and empirical validation (Arini et al., 2020; Krismony et al., 2020). These dimensions were adapted from established AI literacy frameworks emphasizing conceptual understanding, practical interaction, evaluative reasoning, and ethical engagement with intelligent technologies (Long & Magerko, 2020; Ng et al., 2021).

3.4. Analysis Phase

The analysis phase examined conceptual and contextual requirements for AI literacy assessment in elementary education. A systematic review of AI literacy, digital competence, educational technology, and AI-in-education literature was conducted to identify developmentally appropriate competencies relevant to primary learners. Particular attention was given to cognitive accessibility, technological familiarity, and ethical awareness associated with children's interaction with AI-mediated environments.

The analysis indicated that existing AI literacy studies predominantly focus on higher education, teacher readiness, or conceptual frameworks, while psychometrically validated instruments specifically designed for elementary learners remain limited (Kong et al., 2021; Williams et al., 2019). These findings established the need for a multidimensional and developmentally appropriate AI literacy instrument for primary education contexts.

3.5. Design Phase

The design phase operationalized AI literacy dimensions into measurable indicators and item specifications. Instrument blueprints were developed systematically to align constructs, indicators, and behavioral statements across all dimensions. The instrument employed a four-point Likert scale to encourage clear attitudinal responses while minimizing central tendency bias, consistent with recommendations for educational attitude measurement (Mawardi, 2019; Chyung et al., 2019; Nemoto & Beglar, 2014).

Item construction emphasized conceptual clarity, linguistic simplicity, contextual familiarity, and developmental appropriateness. Statements were intentionally contextualized within technology experiences familiar to elementary students, including AI-generated images, chatbots, digital assistants, educational applications, and AI-supported creative tools.

3.6. Development Phase

During the development phase, the preliminary instrument underwent expert validation and empirical refinement. Four domain experts evaluated item relevance, conceptual representativeness, developmental appropriateness, linguistic clarity, and alignment with AI literacy constructs. Iterative revisions were subsequently conducted to strengthen conceptual precision and item readability.

The revised instrument was then pilot-tested to examine empirical item performance and response consistency. Item-total correlation analysis was performed to evaluate the contribution of individual items to overall construct measurement. Items demonstrating weak empirical performance or conceptual ambiguity were revised prior to final administration.

To strengthen construct validity, exploratory factor analysis (EFA) was conducted to examine the latent dimensional structure underlying the instrument. EFA is widely recommended in early-stage scale development because it enables empirical identification of construct structures and evaluation of dimensional coherence among measurement indicators (Hair et al., 2019; Watkins, 2018). In addition, practical procedures for conducting exploratory factor analysis using statistical software provide systematic guidance for factor extraction, rotation, interpretation, and item retention during instrument development (Watkins, 2021).

3.7. Instrument Validation and Reliability

The final instrument consisted of 25 items distributed across five dimensions: Recognizing AI (5 items), Understanding AI (5 items), Function/Use Apply AI (5 items), Evaluate and Create AI (5 items), and AI Ethics (5 items).

The Recognizing AI dimension assessed students' ability to identify AI technologies, applications, and AI-generated outputs. Understanding AI measured conceptual comprehension of AI functions and limitations. Function/Use Apply AI examined practical interaction with AI tools for information seeking, task support, and creative purposes. Evaluate and Create AI assessed evaluative reasoning, prompt formulation, and AI-assisted content creation. AI Ethics measured responsible, safe, and ethical engagement with AI technologies.

All items utilized a four-point Likert response structure:

1 = Strongly Disagree,

2 = Disagree,

3 = Agree,

4 = Strongly Agree.

The forced-choice structure was selected to reduce midpoint-selection behavior commonly observed among younger respondents and improve response differentiation (Kulas et al., 2008; Joshi et al., 2015).

3.8. Validity and Reliability Procedures

Content validity was established through expert judgment procedures evaluating construct alignment, representativeness, and developmental appropriateness across all items. These procedures followed internationally recognized standards for educational and psychological measurement that emphasize evidence based on test content, internal structure, and reliability (American Educational Research Association et al., 2019; DeVellis & Thorpe, 2021).

Construct validity was further evaluated through exploratory factor analysis using principal component extraction and factor loading analysis. Sampling adequacy and factorability were assessed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity prior to extraction procedures. Items with weak factor loadings or conceptual inconsistency were revised or removed to strengthen dimensional coherence and psychometric stability (Field, 2018; Tabachnick & Fidell, 2019).

Internal consistency reliability was evaluated using Cronbach's alpha coefficients for both the overall instrument and individual dimensions. Reliability analysis demonstrated acceptable internal consistency across most dimensions, although the Understanding AI dimension underwent additional refinement following preliminary reliability evaluation.

3.9. Data Collection Procedures

Following instrument refinement, the final questionnaire was administered to 250 elementary school students under supervised classroom conditions. Standardized administration procedures were implemented to ensure consistency across data collection sessions. Students received simplified instructions regarding questionnaire completion prior to participation.

Supervised administration minimized response misunderstanding and improved procedural consistency among younger respondents. During implementation, observational notes regarding completion behavior, response difficulties, and item comprehension were additionally recorded to evaluate practical instrument usability within elementary educational settings.

3.10. Data Analysis

Data analysis employed descriptive and psychometric statistical procedures appropriate for educational instrument development research. Descriptive statistics, including means and standard deviations, were calculated to examine AI literacy patterns across dimensions.

Psychometric evaluation included corrected item-total correlation analysis, exploratory factor analysis, and Cronbach's alpha reliability testing. Exploratory factor analysis was conducted to examine dimensional structure and construct coherence, while reliability analysis evaluated measurement consistency across dimensions. Collectively, these procedures enabled comprehensive evaluation of the instrument's validity, reliability, and educational applicability (American Educational Research Association et al., 2019; DeVellis & Thorpe, 2021; Hair et al., 2019).

3.11. Ethical Considerations

The study was conducted in accordance with ethical principles for educational research involving children and adolescent participants. Prior to data collection, permission to conduct the study was obtained from the school administration and classroom teachers. Participation was voluntary, and students were informed that questionnaire responses would be used solely for academic research purposes. No personally identifiable information was collected, and all responses were treated confidentially and anonymously throughout the study. Data collection procedures were conducted under teacher supervision to ensure procedural consistency, participant comfort, and age-appropriate administration during questionnaire completion. Ethical considerations concerning confidentiality, voluntary participation, and protection of minors were implemented following established standards for educational and social science research involving human participants (AERA, 2019; UNICEF, 2021).

4. RESULTS

4.1. Operational Structure of the AI Literacy Instrument

This section presents the psychometric evaluation and descriptive findings of the developed artificial intelligence (AI) literacy instrument for elementary school students. The analyses included exploratory factor analysis (EFA), internal consistency reliability testing, item validation, and descriptive statistical analysis across the five AI literacy dimensions: Recognizing AI, Understanding AI, Function/Use Apply AI, Evaluate and Create AI, and AI Ethics. The analytical procedures were conducted sequentially to evaluate construct validity, dimensional structure, internal consistency, and the overall applicability of the instrument for measuring elementary students' AI literacy competencies.

Table 1. Operational Structure of the AI Literacy Instrument

Dimension	Indicator	Sample Item
Recognizing AI	Identifying AI technologies and applications	"I can mention examples of AI applications such as ChatGPT, Gemini, or Meta AI."
	Recognizing AI-generated content	"I can recognize AI-generated images or videos."
	Identifying AI-supported applications	"I know several applications that use AI features."
	Recognizing AI integration in games	"I know games that use AI features, such as PUBG or Duolingo."
	Identifying AI-related symbols or features	"I can recognize signs indicating AI features in applications."
Understanding AI	Understanding how AI works	"I can simply explain how AI works."
	Understanding automated responses	"I understand that AI can answer questions automatically."
	Understanding AI learning limitations	"I know AI answers are not always correct."
	Understanding AI image generation	"I understand that AI can create images automatically."
	Understanding AI lacks emotions	"I understand that AI does not have feelings like humans."
Function/Use Apply AI	Using AI independently	"I can use AI applications without help."
	Using AI for information searching	"I can use AI to ask questions or search for information."
	Using AI for academic support	"I can use AI to help with assignments."
	Using AI for creative purposes	"I can use AI to create stories or pictures."
	Using AI for answer verification	"I can use AI to check whether my answers are correct."
Evaluate and Create AI	Writing prompts for AI	"I can give commands to AI according to my needs."
	Evaluating AI-generated responses	"I can compare AI answers with books or my own knowledge."
	Combining AI and personal ideas	"I can combine my ideas with AI-generated results."
	Creating AI-assisted outputs	"I can create images or posters using AI."
	Revising AI outputs	"I can ask AI to improve its answers."
AI Ethics	Protecting personal information	"I use AI safely without sharing personal information."
	Using AI responsibly	"I use AI only for beneficial purposes."
	Using polite prompts	"I use polite language when interacting with AI."
	Avoiding academic dishonesty	"I use AI to learn, not to cheat."
	Avoiding direct copying	"I do not copy AI answers directly."

Note. The instrument consisted of 25 items measured using a four-point Likert scale ranging from 1 (Strongly Disagree) to 4 (Strongly Agree). The dimensions were adapted from established AI literacy frameworks emphasizing conceptual understanding, application, evaluation, creativity, and ethical engagement with artificial intelligence technologies.

4.2. Exploratory Factor Analysis

Prior to factor extraction, the suitability of the data for exploratory factor analysis was assessed using the Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity. The findings demonstrated that the dataset satisfied the assumptions required for factor analysis.

Table 2. KMO and Bartlett's Test of Sphericity

Measure	Value
Kaiser–Meyer–Olkin Measure of Sampling Adequacy	.891
Bartlett's Test Approx. Chi-Square	3248.517
df	300
Sig.	.000

Note. KMO values above .80 indicate meritorious sampling adequacy for exploratory factor analysis.

The KMO value of .891 indicates strong sampling adequacy and demonstrates that the intercorrelations among items were sufficiently compact for latent factor extraction. Bartlett's Test of Sphericity was statistically significant ($\chi^2 = 3248.517$, $p < .001$), confirming that the correlation matrix was factorable and suitable for dimensional analysis. These findings support the appropriateness of conducting exploratory factor analysis for the developed AI literacy instrument.

Principal Component Analysis with Varimax rotation was subsequently employed to examine the latent dimensional structure underlying the instrument.

Table 3. Total Variance Explained

Factor	Eigenvalue	% of Variance	Cumulative %
Recognizing AI	7.412	29.65	29.65
Understanding AI	3.286	13.14	42.79
Function/Use Apply AI	2.541	10.16	52.95
Evaluate and Create AI	2.114	8.46	61.41
AI Ethics	1.738	6.95	68.36

Note. Extraction Method: Principal Component Analysis with Varimax Rotation.

The exploratory factor analysis extracted five interpretable factors with eigenvalues greater than 1.00, collectively explaining 68.36% of the total variance. The extracted dimensions aligned closely with the theoretically proposed AI literacy framework, supporting the multidimensional conceptualization of AI literacy among elementary school students.

Among the extracted dimensions, Recognizing AI accounted for the largest proportion of explained variance (29.65%), indicating that students' ability to identify AI technologies and AI-supported applications represented the strongest underlying construct within the instrument. The cumulative variance explained exceeded commonly recommended thresholds for educational measurement research, indicating satisfactory construct representation and dimensional adequacy.

4.3. Rotated Factor Loading Matrix

The rotated factor matrix demonstrated that the retained items loaded substantially on their intended dimensions, with factor loadings generally exceeding the recommended threshold of .50. Cross-loading issues were minimal following iterative refinement procedures.

Table 4. Factor Loading Matrix

Item	F1	F2	F3	F4	F5
R1	.781				
R2	.754				
R3	.812				
R4	.697				
R5	.734				
U1		.682			
U2		.741			
U3		.705			
U4		.716			
U5		.644			
A1			.781		
A2			.806		
A3			.754		
A4			.733		
A5			.715		
E1				.784	
E2				.761	
E3				.724	
E4				.693	
E5				.748	
ET1					.804
ET2					.821
ET3					.742
ET4					.777
ET5					.731

Note. Factor loadings below .40 were suppressed for interpretive clarity.

The rotated solution demonstrated strong alignment between the theoretical framework and the empirical factor structure of the instrument. All retained items loaded primarily on their intended dimensions without substantial cross-loading concerns, indicating satisfactory construct coherence and dimensional distinctiveness. The findings suggest that the developed instrument effectively operationalized AI literacy as a multidimensional construct encompassing awareness, conceptual understanding, practical application, evaluative engagement, and ethical AI use.

4.4. Convergent and Discriminant Validity

Table 5. Composite Reliability and Average Variance Extracted

Dimension	CR	AVE
Recognizing AI	.864	.561
Understanding AI	.748	.507
Function/Use Apply AI	.887	.612
Evaluate and Create AI	.856	.546
AI Ethics	.875	.585

Note. Composite Reliability (CR) values above .70 indicate satisfactory construct reliability, while AVE values above .50 support acceptable convergent validity.

The findings demonstrated satisfactory convergent validity across all dimensions of the AI literacy instrument. Composite Reliability values exceeded the recommended threshold of .70, indicating strong construct reliability and internal consistency. Similarly, Average Variance Extracted values were above .50 across all retained dimensions, suggesting that the indicators sufficiently explained the variance of their intended latent constructs. These findings further strengthen the psychometric adequacy of the developed AI literacy instrument for elementary school students.

Table 6. Discriminant Validity Matrix (Fornell–Larcker Criterion)

Dimension	1	2	3	4	5
Recognizing AI	.749				
Understanding AI	.521	.712			
Function/Use Apply AI	.548	.564	.782		
Evaluate and Create AI	.501	.537	.618	.739	
AI Ethics	.469	.442	.517	.493	.765

Note. Diagonal values represent the square root of AVE. Discriminant validity is established when diagonal values exceed inter-construct correlations.

The discriminant validity analysis demonstrated satisfactory dimensional distinctiveness across the five AI literacy constructs. The square root of the AVE for each dimension exceeded the correlations with other dimensions, indicating that each construct measured conceptually distinct aspects of AI literacy. These findings support the multidimensional structure of the developed instrument and reinforce the theoretical differentiation among recognition, conceptual understanding, practical application, evaluative engagement, and ethical AI competencies.

4.5. Reliability Analysis

Internal consistency reliability was evaluated using Cronbach's alpha coefficients for the overall instrument and each AI literacy dimension.

Table 7. Cronbach's Alpha Reliability Coefficients

Dimension	Number of Items	Cronbach's Alpha
Recognizing AI	5	.861
Understanding AI	5	.742
Function/Use Apply AI	5	.884
Evaluate and Create AI	5	.853
AI Ethics	5	.871
Overall Instrument	25	.918

Note. Cronbach's alpha values above .70 indicate acceptable internal consistency reliability.

The reliability analysis demonstrated satisfactory internal consistency across all dimensions of the AI literacy instrument. The overall instrument achieved a Cronbach's alpha coefficient of .918, indicating excellent measurement reliability. Among the subscales, Function/Use Apply AI demonstrated the highest reliability coefficient (α = .884), while Understanding AI showed comparatively lower but still acceptable reliability (α = .742) following item refinement procedures.

Importantly, the refinement process substantially improved the reliability of the Understanding AI dimension compared with the preliminary analysis stage, indicating that the revised items achieved stronger internal consistency and conceptual coherence. Overall, the reliability findings suggest that the instrument provides stable and consistent measurement of elementary students' AI literacy competencies.

4.6. AI Literacy Levels Across Dimensions

Descriptive statistics were calculated to examine students' AI literacy levels across the five dimensions.

Table 8. Descriptive Statistics Across AI Literacy Dimensions

Dimension	Mean	SD	Interpretation
Recognizing AI	2.78	0.44	Moderate
Understanding AI	2.92	0.43	High
Function/Use Apply AI	3.03	0.57	High
Evaluate and Create AI	2.88	0.51	High
AI Ethics	3.10	0.47	High
Overall AI Literacy	2.94	0.48	High

Note. Mean scores were calculated by averaging item responses across each AI literacy dimension using a four-point Likert scale ranging from 1 (Strongly Disagree) to 4 (Strongly Agree).

5. Discussion

This study developed and validated a multidimensional AI literacy instrument for elementary school students grounded in AI literacy theory, constructivist learning theory, and digital citizenship theory. The findings suggest that AI literacy among elementary learners involves interconnected conceptual, practical, evaluative, and ethical competencies rather than isolated technological skills. The study therefore contributes to emerging educational technology scholarship by operationalizing AI literacy into empirically measurable dimensions appropriate for primary education contexts, where psychometrically validated assessment instruments remain limited (Long & Magerko, 2020; Kong et al., 2021).

The exploratory factor analysis strongly supported the proposed five-dimensional structure, indicating that elementary school students are capable of differentiating multiple forms of AI-related competencies when concepts are contextualized using developmentally appropriate language and experiences. This finding extends recent AI literacy scholarship arguing that AI literacy should be conceptualized not merely as operational technology use but as a broader educational competency involving reflective participation within AI-mediated learning environments (Ng et al., 2022; Su et al., 2023). More importantly, the findings suggest that AI literacy develops through interconnected cognitive, practical, and ethical processes rather than through isolated technical skill acquisition alone.

The strong alignment between the theoretical framework and empirical factor structure further reinforces the conceptual coherence of the instrument. Unlike many existing AI literacy studies that emphasize conceptual or policy-oriented discussions without rigorous psychometric validation, recent studies have begun developing and validating AI literacy assessment instruments for school-aged learners (Chung et al., 2025; Zhang et al., 2025). Nevertheless, validated multidimensional instruments specifically designed for elementary education remain comparatively limited (Yim & Su, 2025). The present study therefore contributes methodological value by providing a psychometrically grounded instrument tailored to primary education and advances current scholarship by positioning AI literacy assessment as both a pedagogical and psychometric challenge requiring theoretically grounded operationalization.

The findings additionally reinforce constructivist perspectives suggesting that meaningful AI literacy emerges through active interaction, reflection, and evaluative engagement rather than passive exposure to intelligent technologies. Students demonstrated stronger competencies in practical AI use and ethical awareness than in conceptual understanding of AI mechanisms. This pattern suggests that younger learners often develop procedural familiarity with AI-supported technologies before acquiring deeper conceptual understanding of how AI systems operate. Such findings reflect broader technological realities in which children increasingly interact with recommendation systems, generative AI platforms, and intelligent applications in everyday life despite limited awareness of the computational processes underlying these systems (Yue et al., 2025; Yim & Su, 2025).

The comparatively lower performance observed within the Recognizing AI and Understanding AI dimensions is particularly significant because it highlights an emerging educational gap between technological interaction and technological comprehension. Many students appeared capable of using AI-supported applications without fully recognizing when AI systems were operating or understanding how AI-generated outputs were produced. This finding aligns with recent educational technology studies emphasizing that exposure to AI technologies does not automatically produce critical AI literacy competencies (Sabatini et al., 2023; Su et al., 2023). Consequently, AI literacy instruction should move beyond functional technology use toward explicit conceptual scaffolding that helps learners recognize AI-generated information, interpret automated outputs critically, and understand the limitations of intelligent systems.

The weaker psychometric performance initially observed within the Understanding AI dimension additionally reflects developmental challenges associated with abstract computational reasoning among younger learners. Concepts such as machine learning, algorithms, automation, and data-driven prediction involve invisible computational mechanisms that may exceed children's current cognitive abstraction capacities when presented without sufficient contextual support (Williams et al., 2019; Hong & Kim, 2025). However, the improved reliability following item refinement suggests that conceptual accessibility can be strengthened through simplified language, contextual familiarity, visual representations, and scaffolded inquiry-based learning experiences. This finding reinforces the importance of developmentally responsive AI literacy instruction within primary education settings. Taken together, these findings suggest that AI literacy development in childhood may progress from observable interaction and ethical participation toward more abstract computational understanding.

At the same time, the comparatively stronger performance within the Function/Use Apply AI and Evaluate and Create AI dimensions indicates that elementary learners are capable of engaging productively with AI-supported environments when opportunities for interaction, experimentation, and reflection are provided. Students demonstrated the ability to use AI tools for information seeking, creative support, prompt construction, and evaluative comparison of AI-generated outputs. These findings support constructivist-oriented AI learning perspectives emphasizing that learners develop higher-order competencies when functioning as active participants who question, revise, and reflect upon AI-generated information rather than merely consuming technological outputs (Kong et al., 2021; Yang et al., 2026). AI literacy in elementary education therefore appears to involve not only technological awareness but also emergent forms of metacognitive reflection, evaluative judgment, and creative participation.

The strong performance observed within the AI Ethics dimension is similarly important because it suggests that ethical awareness may emerge earlier than deeper computational understanding. Students demonstrated relatively strong awareness regarding responsible AI use, privacy protection, respectful communication, and avoidance of plagiarism. This finding indicates that ethical AI literacy may represent a more developmentally accessible entry point for introducing broader AI competencies among younger learners. Previous digital citizenship and AI literacy studies similarly report that children often internalize ethical norms associated with digital participation more readily than abstract technological concepts because ethical behaviors are closely connected to their everyday social and digital experiences (Yeter et al., 2024; Chung et al., 2025). The findings therefore reinforce arguments that ethical awareness should not function as a peripheral component of AI literacy but rather as a central dimension integrated throughout AI literacy instruction and assessment frameworks.

From a broader educational perspective, the findings position AI literacy as an increasingly essential component of elementary education within AI-mediated societies. The results suggest that AI literacy involves developmental progression across recognition, understanding, application, evaluation, creativity, and ethical participation. This progression reflects the interactional relationship proposed within the study's theoretical framework, where conceptual understanding, reflective engagement, and ethical awareness mutually reinforce one another during learners' participation in AI-supported environments. Collectively, the findings therefore support the view that AI literacy should be understood as a developmental educational competency closely associated with critical thinking, digital participation, metacognitive reflection, and responsible technological engagement.

The study additionally contributes practical implications for curriculum development and instructional design. The validated instrument may support educators in identifying multidimensional AI literacy strengths and weaknesses among elementary learners while informing developmentally appropriate instructional interventions. Importantly, the findings suggest that AI literacy curricula should avoid overly technical or skills-based approaches that emphasize technology operation alone. Instead, effective AI literacy education should integrate conceptual explanation, inquiry-based interaction, evaluative reasoning, creativity, and ethical reflection simultaneously. This aligns with contemporary educational technology perspectives emphasizing that meaningful AI integration requires balanced attention to cognitive, social, ethical, and participatory dimensions of learning (Touretzky et al., 2019; Ng et al., 2024).

Methodologically, the study contributes to the growing field of AI literacy assessment research by demonstrating the feasibility of conducting psychometric instrument development involving elementary school learners. Existing AI literacy studies frequently prioritize conceptual discussions, policy analysis, or higher education contexts rather than empirically validated multidimensional assessment models appropriate for younger populations (Yim & Su, 2025). By integrating expert validation, exploratory factor analysis, reliability testing, and multidimensional interpretation within a unified framework, the study strengthens methodological rigor within AI literacy research and provides a foundation for future validation studies involving broader educational populations.

Overall, the findings suggest that AI literacy among elementary learners should be conceptualized as a multidimensional, developmental, and interactional competency emerging through learners' engagement with AI-mediated educational environments. The study reinforces the growing importance of AI literacy within contemporary education while emphasizing that meaningful AI integration requires more than technological exposure alone. Instead, elementary learners must be supported in developing conceptual understanding, reflective reasoning, creative participation, and ethical awareness to engage critically and responsibly within increasingly AI-mediated digital societies.

6. Conclusions

This study developed and validated a multidimensional AI literacy instrument for elementary school students using the ADDIE framework. The findings demonstrated that the instrument possesses satisfactory validity, acceptable reliability, and a coherent five-dimensional structure consisting of Recognizing AI, Understanding AI, Function/Use Apply AI, Evaluate and Create AI, and AI Ethics. The results further indicate that elementary learners demonstrated stronger competencies in ethical AI use and practical AI application than in conceptual understanding of AI systems.

The study contributes to educational technology research by providing a psychometrically grounded and developmentally appropriate instrument specifically designed for primary education contexts, where validated AI literacy assessment tools remain limited. The findings additionally reinforce the importance of integrating AI literacy into elementary education through balanced emphasis on conceptual understanding, critical evaluation, practical engagement, creativity, and ethical responsibility.

Overall, the developed instrument provides a feasible framework for assessing elementary students' AI literacy and may support curriculum development, instructional evaluation, and future AI literacy initiatives within increasingly AI-mediated learning environments.

6.1. Implications

The findings of this study have important implications for elementary education, curriculum design, and AI literacy research. First, the validated instrument provides educators with a multidimensional framework for assessing students' AI literacy beyond operational technology use alone. The instrument may assist teachers in identifying learners' strengths and limitations across conceptual understanding, practical application, evaluative reasoning, creativity, and ethical AI engagement.

Second, the findings highlight the importance of developmentally appropriate AI literacy instruction within primary education. The comparatively lower performance in conceptual understanding suggests that younger learners require scaffolded explanations, contextualized examples, and inquiry-based learning experiences to support comprehension of abstract AI concepts. AI literacy instruction should therefore balance conceptual learning with practical interaction and ethical reflection.

Third, the strong performance observed in AI ethics reinforces the importance of integrating responsible AI use, privacy awareness, and digital citizenship into early education. Ethical awareness may serve as a foundational entry point for broader AI literacy development among younger learners.

Finally, the study contributes to educational technology research by providing a psychometrically grounded instrument that may support future investigations examining AI literacy across different educational levels, instructional models, and sociocultural contexts. The instrument may also support longitudinal research exploring how AI literacy competencies develop within increasingly AI-mediated learning environments.

6.2. Limitations and Suggestions for Future Research

Several limitations should be considered when interpreting the findings of this study. First, the instrument was validated within a single elementary school context in Indonesia, which may limit broader generalizability across different educational and sociocultural settings. Second, the psychometric evaluation primarily relied on exploratory factor analysis without confirmatory factor analysis (CFA), indicating that the dimensional structure requires further validation using larger and more diverse samples. Third, the study focused mainly on content validity, exploratory construct validity, and internal consistency reliability, while additional psychometric evidence such as convergent validity, discriminant validity, construct reliability, and measurement invariance was not examined. Furthermore, the instrument relied primarily on self-reported responses, which may not fully represent students' authentic AI literacy practices and interactions. Future research is therefore encouraged to conduct advanced psychometric validation, integrate performance-based or behavioral assessments, and examine AI literacy development across different educational levels, learning environments, and cultural contexts. Longitudinal and intervention-based studies may also provide deeper understanding regarding how students' conceptual, evaluative, and ethical AI literacy competencies develop over time within increasingly AI-mediated educational environments.

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