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Design Inquiry for AI Literacy Framework Development: Evidence from Indonesian Pre-service Primary School Teachers in Teaching English to Young Learners

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ABSTRACT

Perkembangan kecerdasan artifisial (*Artificial Intelligence*/AI) telah menghadirkan peluang sekaligus tantangan baru bagi pendidikan guru sehingga calon guru perlu memiliki kompetensi untuk memanfaatkan AI secara bertanggung jawab, etis, dan sesuai dengan prinsip pedagogis. Penelitian ini bertujuan mengidentifikasi kebutuhan pendidikan yang menjadi dasar pengembangan kerangka literasi AI bagi mahasiswa Pendidikan Guru Sekolah Dasar (PGSD) di Indonesia yang dipersiapkan untuk mengajar *Teaching English to Young Learners* (TEYL). Penelitian menggunakan Design Inquiry dengan pendekatan *mixed methods* sebagai operasionalisasi tahap *Analysis and Exploration* dalam *Educational Design Research*. Data kuantitatif dikumpulkan melalui angket yang dikembangkan berdasarkan *UNESCO AI Competency Framework for Teachers* (AI CFT), sedangkan data kualitatif diperoleh melalui wawancara semi-terstruktur, observasi, dan analisis dokumen. Hasil penelitian mengidentifikasi lima kebutuhan pendidikan, yaitu penguatan pemahaman konseptual AI, pengembangan pedagogi AI untuk TEYL, penguatan praktik AI yang berpusat pada manusia dan beretika, pengembangan profesional berkelanjutan berbasis AI, serta penguatan dukungan institusional terhadap literasi AI. Kebutuhan tersebut selanjutnya diterjemahkan menjadi lima persyaratan desain, lima kompetensi inti literasi AI, dan lima belas indikator kompetensi yang dapat diamati, yang kemudian disintesiskan ke dalam Empirical Design Requirements Matrix (DRM). Kontribusi utama penelitian ini adalah menghasilkan (DRM) berbasis bukti empiris yang menjadi landasan bagi pengembangan dan validasi kerangka literasi AI untuk mahasiswa Pendidikan Guru Sekolah Dasar (PGSD) di Indonesia.

Artificial intelligence (AI) has created new opportunities and challenges for teacher education, requiring pre-service teachers to develop competencies that support the responsible and pedagogically appropriate use of AI in classroom practice. This study identifies the educational needs that should inform the development of an AI literacy framework for Indonesian pre-service primary school teachers preparing to teach English to Young Learners (TEYL). The study employed a mixed-method Design Inquiry, operationalising the Analysis and Exploration phase of Educational Design Research. Quantitative data were collected through a questionnaire based on the UNESCO AI Competency Framework for Teachers (AI CFT); qualitative evidence came from semi-structured interviews, classroom observations, and document analysis. The findings revealed five educational needs: strengthening conceptual AI understanding, developing AI-enhanced pedagogy for TEYL, promoting human-centred and ethical AI practice, supporting continuous professional learning, and strengthening institutional support for AI literacy. These needs were translated into five design requirements, five core AI literacy competencies, and fifteen observable competency indicators, synthesised into an Empirical Design Requirements Matrix (DRM). The DRM is the principal outcome of this study: it links authentic educational evidence directly to design specifications for AI literacy framework development, providing an empirical foundation for constructing and validating a framework responsive to the needs of Indonesian pre-service primary school teachers.

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INTRODUCTION

Artificial intelligence (AI) is transforming education by changing how teachers design instruction, develop learning materials, assess student learning, and pursue professional development. The rapid adoption of generative AI has created new opportunities for teaching and learning, and it has raised expectations that teachers can use AI responsibly, critically evaluate AI-generated content, address ethical issues, and integrate AI into pedagogically meaningful classroom practice (Holmes et al., 2022; Miao & Cukurova, 2024). Recent scholarship conceptualises AI literacy as a multidimensional competency that extends beyond technical skills to include critical understanding, ethical reasoning, and informed decision-making (Long & Magerko, 2020; Ng et al., 2021). AI literacy has therefore become an essential component of teacher professionalism.

AI literacy matters in teacher education because pre-service teachers must develop these competencies before entering professional practice, particularly in Teaching English to Young Learners (TEYL), where instructional decisions must account for children's cognitive, linguistic, and socio-emotional development. AI can support lesson planning, material development, formative assessment, and differentiated instruction, but its educational value depends on teachers' ability to adapt AI-generated resources to learners' developmental needs while maintaining professional judgement and ethical responsibility (Kusmaryati, 2020; Diyanti et al., 2020; Astutik & Munir, 2022; Wahyuni, 2024).

Recent studies describe AI literacy as a multidimensional construct encompassing foundational AI knowledge, pedagogical integration, ethical responsibility, critical evaluation, and reflective professional practice (Long & Magerko, 2020; Ng et al., 2021; Ayanwale et al., 2024). Emerging competency frameworks further hold that teachers should integrate AI while preserving human agency, professional judgement, and responsible educational practice (Filo et al., 2024; Mikeladze et al., 2024; Miao & Cukurova, 2024). This study adopts the UNESCO AI Competency Framework for Teachers (AI CFT) as its conceptual foundation for examining AI literacy among Indonesian pre-service primary school teachers.

Despite these advances, an important research gap remains. Existing studies have focused mainly on conceptualising AI literacy, exploring teachers' perceptions, or examining AI adoption in teacher education (Kim & Kwon, 2023; Butler & Jiang, 2025; Karaduman, 2025). More recent research has begun investigating generative AI within English language teacher education and teaching-practicum contexts (Kusuma et al., 2024; Huang et al., 2025), yet comparatively little work has translated authentic educational evidence into explicit design specifications that can guide AI literacy framework development. The gap is especially pronounced in Indonesia, where empirical evidence on AI literacy among pre-service primary school teachers preparing to teach English to Young Learners remains limited (Zulkarnain & Yunus, 2023). Existing competency frameworks therefore offer insufficient empirical guidance for developing contextually relevant AI literacy frameworks in teacher education.

Educational Design Research (EDR) offers a methodological approach suited to this gap: it emphasises the systematic development of educational solutions grounded in empirical evidence (McKenney & Reeves, 2018; Hall, 2020). Within EDR, Design Inquiry enables researchers to integrate multiple sources of evidence and identify educational needs before proposing design solutions (Halverson & Halverson, 2020; Hanghøj et al., 2022; Lehtonen, 2021). This study operationalises the Analysis and Exploration phase of EDR through a mixed-method Design Inquiry that integrates quantitative and qualitative evidence to identify educational needs before framework development begins. Instead of adopting an existing competency framework directly, the Design Inquiry derives educational needs from authentic educational evidence and translates them into design requirements, core AI literacy competencies, observable competency indicators, and an Empirical Design Requirements Matrix (DRM).

This study therefore aims to identify the educational needs that should inform the development of an AI literacy framework for Indonesian pre-service primary school teachers in the context of

Teaching English to Young Learners. Using a mixed-method Design Inquiry, the study integrates evidence from questionnaires, interviews, observations, and document analysis to produce an evidence-informed Empirical Design Requirements Matrix (DRM). The DRM constitutes the principal outcome of Research 1 and provides the empirical foundation for the subsequent construction and validation of the AI Literacy Framework within the broader Educational Design Research programme.

METHOD

This study employed a mixed-method Design Inquiry in which quantitative questionnaire data were followed by qualitative evidence from semi-structured interviews, classroom observations, and document analysis. The Design Inquiry operationalised the Analysis and Exploration phase of Educational Design Research (EDR) (McKenney & Reeves, 2018; Hall, 2020). The Design Inquiry investigated the AI literacy needs of Indonesian pre-service primary school teachers before the development of an AI literacy framework. The study first generated authentic educational evidence to identify educational needs, formulate design requirements, derive core AI literacy competencies, and establish observable competency indicators; these analytical products were then synthesised into an Empirical Design Requirements Matrix (DRM), the principal outcome of Research 1. This approach reflects the iterative, evidence-informed principles of Educational Design Research, in which empirical findings provide the foundation for subsequent design and framework development (McKenney & Reeves, 2018; Halverson & Halverson, 2020).

The study was conducted with pre-service primary school teachers enrolled in the Primary School Teacher Education (Pendidikan Guru Sekolah Dasar/PGSD) programme at an Indonesian university. A total of 94 pre-service primary school teachers participated in the questionnaire survey, of whom 93 returned valid questionnaires for quantitative analysis. Participants were selected purposively because they represented the target population for the subsequent AI literacy framework. To enrich and explain the quantitative findings, the researcher selected a smaller group of participants for semi-structured interviews based on variations in AI literacy experiences and questionnaire responses. Additional evidence came from classroom observations and institutional document analysis, providing contextual information on curriculum implementation, AI use, and teacher education practices.

Four complementary instruments were used to collect data. The questionnaire measured participants' AI literacy across five competency domains adapted from the UNESCO AI Competency Framework for Teachers (AI CFT): AI Foundations and Applications, Human-Centered Mindset, AI Ethics, AI Pedagogy for Teachers, and AI for Professional Development (Miao & Cukurova, 2024). Responses were recorded using a five-point Likert scale. Semi-structured interviews explored participants' perceptions of AI use, instructional challenges, ethical considerations, institutional support, and expectations for AI literacy development. Classroom observations examined AI-related learning behaviours during teacher education activities, while document analysis investigated curriculum documents, course materials, and institutional policies relevant to AI integration. Drawing on multiple evidence sources reflects the Design Inquiry principle of understanding educational problems from complementary perspectives before proposing design solutions (Hennessy et al., 2021; Hanghøj et al., 2022).

Quantitative data were analysed using descriptive statistics, including frequencies, percentages, means, and standard deviations, to describe participants' AI literacy profiles across the five UNESCO AI CFT domains. The researcher assessed the internal consistency of the questionnaire using Cronbach's Alpha. Because the questionnaire functioned as one source of evidence within the Design Inquiry, not as a newly developed psychometric instrument, the quantitative analysis emphasised descriptive statistics and reliability analysis. These findings informed the subsequent qualitative phase by identifying issues that required further exploration.

The researcher analysed qualitative data from interviews, observations, and document analysis using thematic analysis. Data were coded inductively and grouped into categories representing participants' educational experiences, AI literacy needs, pedagogical challenges, ethical concerns, and institutional factors influencing AI integration. Observation and document analysis corroborated and contextualised the interview findings, producing a fuller picture of AI literacy within the teacher education programme.

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The quantitative and qualitative findings were integrated through methodological triangulation. Instead of comparing methods independently, the researcher used triangulation to identify convergent patterns across questionnaires, interviews, observations, and document analysis. This synthesised evidence informed the identification of educational needs, which were then translated into design requirements, core AI literacy competencies, and observable competency indicators. These outputs were consolidated into the Empirical Design Requirements Matrix (DRM), providing the empirical foundation for the subsequent development of an AI Literacy Framework in the next stage of the Educational Design Research programme. This process aligns with Educational Design Research, which calls for the systematic translation of empirical evidence into design knowledge through iterative inquiry and evidence-based decision-making (McKenney & Reeves, 2018; Lehtonen, 2021).

Figure 1. Design Inquiry process for developing the Empirical Design Requirements Matrix (DRM).



RESULTS AND DISCUSSION

AI Literacy Profile of Pre-service Primary School Teachers

Ninety-four pre-service primary school teachers enrolled in the Primary School Teacher Education (PGSD) programme participated in the study, with 93 valid questionnaires included in the quantitative analysis. All participants had completed or were undertaking courses related to Teaching English to Young Learners (TEYL) and represented the target population for the proposed AI literacy framework. Most participants reported regular use of AI applications such as ChatGPT, Gemini, Gamma, and Canva, but their experience was mainly self-directed rather than supported through systematic teacher education. Participants therefore showed varying levels of conceptual understanding and pedagogical application despite their frequent engagement with AI technologies.

Table 1. Characteristics of the study participants.

Characteristic	**Value**
Participants	94
Valid questionnaires	93
Study programme	Primary School Teacher Education (PGSD)
Context	Teaching English to Young Learners (TEYL)

The descriptive analysis revealed generally positive perceptions of AI literacy across the five competency domains adapted from the UNESCO AI Competency Framework for Teachers (AI CFT). Human-Centered Mindset obtained the highest mean score (M = 3.82), followed by AI Ethics (M =

3.75). AI Foundations and Applications (M = 3.58), AI Pedagogy for Teaching English to Young Learners (M = 3.56), and AI for Professional Development (M = 3.49) scored more moderately. At the item level, participants expressed the strongest agreement with maintaining teacher responsibility when using AI (M = 4.06), while the lowest score concerned using AI to prepare English assessments for primary school learners (M = 3.25). These findings suggest that participants felt more confident about the ethical principles of AI use than about applying AI to pedagogically demanding instructional tasks.

Table 2. Descriptive statistics of AI literacy competency domains.

AI Literacy Profile Across the Five UNESCO AI CFT Domains

AI Competency Domain	**Mean**
AI Foundations and Applications	3.58
Human-Centered Mindset	3.82
AI Ethics	3.75
AI Pedagogy for TEYL	3.56
AI for Professional Development	3.49
Cronbach's Alpha	0.923

The questionnaire also showed excellent internal consistency, with a Cronbach's Alpha coefficient of 0.923. This result indicates that the instrument measured the five AI literacy domains reliably and was appropriate for informing the subsequent qualitative phase of the Design Inquiry. Instead of functioning as a psychometric validation study, the quantitative findings served to identify competency patterns that required further exploration through interviews, observations, and document analysis.

Overall, the quantitative findings reveal a clear pattern. Participants expressed positive attitudes toward AI and recognised the importance of maintaining teacher agency and ethical responsibility, yet they reported lower confidence in foundational AI knowledge, pedagogical application, and AI-supported professional learning. Long and Magerko (2020) describe this same pattern: AI literacy extends beyond operational proficiency to include conceptual understanding and informed decision-making. Ng et al. (2021) similarly frame AI literacy as a multidimensional construct integrating technical knowledge, critical evaluation, and responsible application, and Ayanwale et al. (2024) found that pre-service teachers often show favourable attitudes toward AI despite gaps in conceptual competence. Regular exposure to AI technologies, in other words, does not automatically produce educationally meaningful AI literacy. Systematic teacher education is what transforms operational familiarity into pedagogical, ethical, and professional competence. These quantitative findings provided the empirical rationale for the qualitative investigation that followed, aimed at identifying the educational needs that informed the development of the Empirical Design Requirements Matrix (DRM).

Educational Needs Revealed through the Design Inquiry

The Design Inquiry integrated findings from the questionnaire, semi-structured interviews, classroom observations, and document analysis to explain the competency patterns identified in the quantitative phase. Instead of presenting each dataset on its own, methodological triangulation revealed five interrelated educational needs that describe the current state of AI literacy among Indonesian pre-service primary school teachers. These needs provide the empirical basis for subsequent framework development.

Table 3. Educational needs identified through methodological triangulation.

Educational Need	**Questionnaire**	**Interview**	**Observation**	**Document**
Conceptual AI understanding	✓	✓	✓	✓
AI pedagogy for TEYL	✓	✓	✓	—
Human-centred and ethical AI	✓	✓	✓	✓
AI-supported professional learning	✓	✓	✓	✓
Institutional support	—	✓	—	✓

1. *Strengthening Conceptual AI Understanding*

Although participants reported frequent use of AI applications, the evidence consistently pointed to knowledge that remained largely procedural rather than conceptual. The questionnaire showed only

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moderate confidence in AI Foundations and Applications, while interviews revealed that participants learned to use AI mainly through online tutorials, social media, and peer discussions. Many acknowledged limited understanding of AI concepts, terminology, system capabilities, and prompt engineering. Classroom observations confirmed that participants could operate AI tools effectively but often reasoned less deeply when selecting or evaluating AI outputs. Document analysis further showed that AI concepts had not yet been explicitly built into the teacher education curriculum. AI literacy development, these findings indicate, should begin with systematic conceptual understanding rather than focus solely on operational skills. Long and Magerko (2020) reach a comparable conclusion: AI literacy requires a comprehensive understanding of AI concepts, capabilities, and limitations, not simple tool operation. Ng et al. (2021) add that conceptual knowledge forms the foundation for critical and responsible AI use, and Ayanwale et al. (2024) report that pre-service teachers frequently show positive attitudes toward AI despite holding only moderate conceptual understanding. Teacher education programmes should, on this evidence, establish strong conceptual foundations before expecting meaningful pedagogical integration of AI.

2. *Developing AI Pedagogical Competence for Teaching English to Young Learners*

Evidence from all four data sources showed that participants used AI confidently to prepare lesson plans, stories, vocabulary activities, and classroom materials. They reported substantially lower confidence, however, in designing AI-supported assessment and adapting AI-generated resources to the developmental characteristics of young learners. Observational evidence supported these findings: AI outputs were frequently accepted with minimal pedagogical modification. The quantitative findings likewise identified AI-supported assessment as the weakest competency area. Teacher education programmes should strengthen pedagogical decision-making, these results suggest, so that AI becomes an instructional resource rather than merely a productivity tool. Butler and Jiang (2025) found a related pattern: pre-service language teachers recognised the instructional potential of generative AI but needed greater pedagogical support to integrate it effectively into classroom practice. Kusuma et al. (2024) reached a similar conclusion in their study of EFL pre-service teachers, who used ChatGPT primarily to support lesson preparation during teaching practicum. Huang et al. (2025) went further, demonstrating that explicit instructional interventions significantly improved pre-service language teachers' ability to integrate generative AI into pedagogically meaningful teaching. These studies point to the same need: teacher education programmes must move beyond operational AI skills and build pedagogical competence within the specific context of Teaching English to Young Learners.

3. *Strengthening Human-Centered and Ethical AI Practice*

Participants consistently viewed AI as a tool that should support, not replace, teachers' professional judgement. This view produced the highest questionnaire score and came through again in interviews, where participants stressed learner privacy, academic integrity, and responsible instructional decision-making. Classroom observations nonetheless found that participants did not consistently verify AI-generated information or apply ethical evaluation during instructional activities, and institutional documents offered limited guidance on responsible AI use. Ethical awareness alone is not enough; teacher education must also give pre-service teachers structured opportunities to turn ethical principles into routine professional practice. Holmes et al. (2022) support this reading, arguing that ethical AI competence requires continuous professional judgement, critical evaluation of AI-generated outputs, and protection of learner rights throughout educational practice. Miao and Cukurova (2024) identify human agency, ethical responsibility, and accountable AI use as core competencies within the UNESCO AI Competency Framework for Teachers. Teacher education programmes should treat ethical AI as a thread running through the curriculum, not as a separate theoretical topic bolted onto it.

4. *Developing AI Literacy for Continuous Professional Learning*

AI for Professional Development recorded the lowest competency score. Interview findings showed that participants relied mainly on self-directed learning, peer support, and online resources to improve their AI skills, while classroom observations revealed considerable variation in AI practices among individuals. Document analysis confirmed that structured AI-related professional development opportunities for pre-service teachers remained limited. AI literacy should be embedded within continuous professional learning, these findings suggest, rather than treated as a short-term technology initiative. Filo et al. (2024) support this view, treating continuous professional learning as a central component of AI competency development for teachers. Tenberga and Daniela (2024) add that teachers need ongoing opportunities to assess, strengthen, and update their AI competencies as educational

technologies keep evolving. AI literacy, in this light, is a developmental professional competency that extends well beyond initial teacher preparation and continues throughout a teacher's career.

5. *Strengthening Institutional Support for AI Literacy*

The final educational need concerns institutional readiness. Curriculum documents recognised digital technologies within teacher education generally, but AI literacy had not been explicitly built into learning outcomes, curriculum design, or institutional policy. Participants consistently called for structured training, curriculum integration, mentoring, and institutional guidance. Interview, observation, and document evidence converge on one point: sustainable AI literacy development depends not only on individual competencies but also on coordinated institutional support. Connolly et al. (2022) make a related argument, that educational innovation requires coherent curriculum design, institutional commitment, and collaborative implementation rather than isolated instructional initiatives. Mikeladze et al. (2024) add that successful AI competency development depends on supportive institutional ecosystems, including curriculum alignment, organisational policies, and collaborative professional learning. AI literacy is therefore an institutional responsibility as much as an individual one, requiring coordinated support across curriculum, policy, and teacher education practice.

From Educational Needs to the Empirical Design Requirements Matrix

The five educational needs identified through the Design Inquiry were systematically translated into a set of design requirements to guide the development of an AI literacy framework for Indonesian pre-service primary school teachers. Instead of prescribing instructional activities, these design requirements specify the essential characteristics the framework should possess to address the authentic educational conditions identified through methodological triangulation. Each requirement came directly from convergent evidence gathered through questionnaires, interviews, observations, and document analysis, keeping subsequent design decisions grounded in participants' educational experiences rather than in theoretical assumptions alone. This process reflects a central principle of Educational Design Research: empirical evidence is systematically transformed into design knowledge that informs subsequent educational interventions (McKenney & Reeves, 2018; Hall, 2020).

The first design requirement calls for systematic conceptual AI literacy. Although participants regularly used AI applications, the findings consistently showed limited understanding of AI principles, capabilities, and limitations. The framework should therefore prioritise foundational AI knowledge before introducing more advanced pedagogical applications. This requirement responds directly to the need for strengthening conceptual AI understanding and establishes a basis for informed, critical use of AI in educational settings, consistent with AI literacy frameworks that treat conceptual understanding as the foundation for responsible AI use (Long & Magerko, 2020; Ng et al., 2021).

The second design requirement focuses on AI-enhanced pedagogy for Teaching English to Young Learners (TEYL). Participants showed confidence in using AI to generate instructional materials but struggled more with integrating AI into lesson implementation and assessment. The framework should therefore give pre-service teachers opportunities to apply AI throughout instructional planning, classroom activities, formative assessment, and differentiated instruction, with attention to the developmental characteristics of young learners. This recommendation matches recent studies showing that meaningful AI integration in language teacher education demands pedagogical competence, not technological proficiency alone (Butler & Jiang, 2025; Kusuma et al., 2024; Huang et al., 2025).

The third design requirement concerns human-centred and ethical AI practice. Although participants expressed strong support for maintaining teacher responsibility, the empirical evidence revealed a gap between ethical awareness and professional practice. The framework should therefore embed ethical principles across all learning components, promoting critical evaluation of AI-generated information, protection of learner privacy, academic integrity, and teacher agency in instructional decision-making. This aligns with Holmes et al. (2022) and the UNESCO AI Competency Framework for Teachers, both of which place ethical responsibility and human agency at the centre of AI competence in education (Miao & Cukurova, 2024).

The fourth design requirement treats AI-supported professional learning as a continuous process, not a one-time training activity. Participants relied mainly on self-directed learning to build AI competencies, pointing to the need for structured opportunities that encourage reflective practice, collaborative learning, and ongoing professional development. AI literacy should therefore be positioned as a competency that evolves throughout a teacher's career, in line with competency frameworks that

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treat continuous professional learning as an essential dimension of AI literacy development (Filo et al., 2024; Tenberga & Daniela, 2024).

The final design requirement addresses institutional integration of AI literacy. Document analysis showed that AI had not yet been systematically embedded within curriculum design, institutional policy, or professional development. The proposed framework should therefore stay flexible enough to support curriculum enhancement, institutional policy development, and coordinated AI literacy initiatives within teacher education programmes, in line with research on the importance of institutional commitment, curriculum alignment, and organisational support for sustainable AI literacy implementation (Connolly et al., 2022; Mikeladze et al., 2024).

The researcher then operationalised these five design requirements into five core AI literacy competencies: Foundational AI Literacy, AI-Enhanced Pedagogical Competence, Human-Centred and Ethical AI Competence, AI-Supported Professional Learning Competence, and Institutional and Collaborative AI Competence. Each competency represents the knowledge, skills, and professional dispositions required for responsible AI integration in Teaching English to Young Learners, and each corresponds directly to one or more educational needs identified during the Design Inquiry. The competencies function, in this sense, as evidence-informed design constructs that bridge empirical educational needs with subsequent framework development.

To support their practical application, the researcher further translated the five competencies into fifteen observable competency indicators describing the expected performance of pre-service teachers. These indicators span conceptual understanding, pedagogical application, ethical decision-making, reflective professional learning, and institutional collaboration. Unlike the questionnaire items used for data collection, the indicators function as design specifications that can inform curriculum development, instructional planning, and future assessment of AI literacy within teacher education programmes.

Synthesising the educational needs, design requirements, core competencies, and observable competency indicators produced the **Empirical Design Requirements Matrix (DRM)**, the principal outcome of this study. The DRM traces an explicit line between authentic educational evidence and the proposed design specifications, showing how empirical findings informed each component of the future AI literacy framework. The DRM is not the framework itself; it is an evidence-informed design specification that guides the subsequent framework construction, expert validation, and implementation phases of the broader Educational Design Research programme. This reflects a core principle of Educational Design Research: iterative refinement built on explicit connections between empirical evidence and educational design decisions (McKenney & Reeves, 2018; Halverson & Halverson, 2020; Lehtonen, 2021).

From an Educational Design Research perspective, the DRM provides a methodological bridge between educational analysis and educational design. The matrix keeps framework development driven by authentic educational needs rather than by predefined competency models. By linking empirical evidence to design decisions through a transparent, systematic process, the Design Inquiry offers a replicable approach for developing educational frameworks that respond to local contexts while remaining aligned with internationally recognised AI competency principles (McKenney & Reeves, 2018; Hall, 2020; Halverson & Halverson, 2020; Hanghøj et al., 2022; Lehtonen, 2021).

Table 4. Condensed Empirical Design Requirements Matrix (DRM).

Educational Need	**Design Requirement**	**Core AI Literacy Competency**	**Observable Competency Indicator**
Conceptual AI understanding	Systematic conceptual AI learning	Foundational AI Literacy	Explains AI concepts and limitations
AI pedagogy for TEYL	AI-enhanced instructional design	AI-Enhanced Pedagogical Competence	Designs AI-supported TEYL activities
Human-centred and ethical AI	Ethical AI integration	Human-Centred and Ethical AI Competence	Critically evaluates AI outputs
Professional learning	Continuous AI development	AI-Supported Professional Learning Competence	Engages in reflective AI learning
Institutional support	Curriculum and policy integration	Institutional and Collaborative AI Competence	Collaborates in institutional AI initiatives

CONCLUSION

This study investigated the AI literacy needs of Indonesian pre-service primary school teachers preparing to teach English to Young Learners through a mixed-method Design Inquiry situated within the Analysis and Exploration phase of Educational Design Research. By integrating evidence from questionnaires, semi-structured interviews, classroom observations, and document analysis, the study identified five interrelated educational needs that together point to a gap between participants' frequent use of AI technologies and their readiness to integrate AI pedagogically, ethically, and systematically within teacher education. Meaningful AI literacy, these findings show, needs more than operational familiarity with AI tools: it requires coherent development of conceptual understanding, pedagogical competence, ethical practice, continuous professional learning, and institutional support.

The principal contribution of this study is the **Empirical Design Requirements Matrix (DRM)**, which traces an explicit line between authentic educational evidence and framework design specifications. Existing AI competency frameworks mainly describe expected competencies; the DRM instead provides an evidence-informed design specification that systematically translates educational needs into design requirements, core AI literacy competencies, and observable competency indicators. This contribution extends previous research on AI literacy (Long & Magerko, 2020; Ng et al., 2021) by showing how empirical evidence can be systematically transformed into design knowledge through Educational Design Research (McKenney & Reeves, 2018). The DRM therefore serves as the empirical foundation for constructing and validating an AI literacy framework that is both contextually relevant to Indonesian teacher education and aligned with internationally recognised AI competency principles.

The findings also carry practical implications for teacher educators, curriculum developers, and higher education institutions seeking to integrate AI literacy into pre-service teacher education. The Empirical Design Requirements Matrix does not prescribe a fixed curriculum; it offers evidence-informed guidance for curriculum planning, instructional design, competency assessment, and institutional policy development. Higher education institutions can use the matrix to design AI literacy programmes that stay responsive to local educational contexts while aligning with international expectations for responsible AI integration.

Several limitations should be acknowledged. The study involved participants from a single Primary School Teacher Education programme, which may limit how far the findings transfer to other institutional contexts. The Design Inquiry also focused on identifying educational needs and producing an empirical design specification rather than on constructing or evaluating the AI literacy framework itself. The findings should therefore be read as the empirical foundation for framework development, not as evidence of the framework's effectiveness.

Future research should extend this work by using the Empirical Design Requirements Matrix to construct, validate, and implement the proposed AI literacy framework through expert review, iterative refinement, and classroom application. Later stages of the broader Educational Design Research programme should also evaluate the framework's effectiveness in strengthening AI literacy among Indonesian pre-service primary school teachers and examine how well it transfers across diverse teacher education contexts. Such work would further establish the framework's validity and transferability while contributing to the growing body of research on AI literacy in teacher education.

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