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Strengthening Elementary School Teachers' Digital Competence through AI-Based Instructional Design Training in Indonesia's 3T Regions

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ABSTRACT

This quantitative study investigates the effectiveness of an artificial intelligence (AI)-based instructional design training program in strengthening the digital competence of elementary school teachers in Indonesia's frontier, outermost, and underdeveloped (3T) regions. Education quality and access in 3T regions remain constrained by geographical isolation, limited infrastructure, and uneven professional development opportunities for teachers. Building on the European Digital Competence Framework for Educators (DigCompEdu) and its six areas of educator digital competence, the study designed a structured training program that introduced teachers to generative AI tools for lesson planning, resource development, and assessment. A one-group pretest–posttest design was implemented with 120 elementary school teachers from several 3T districts. Data were collected using a Likert-scale digital competence questionnaire adapted from DigCompEdu and analyzed with descriptive statistics and paired-sample t-tests. Findings show statistically significant improvements in teachers' overall digital competence scores across all six DigCompEdu areas, with the largest gains in "Teaching and learning" and "Facilitating learners' digital competence." The results indicate that contextually grounded AI-based instructional design training can be an effective strategy to narrow digital competence gaps between teachers in peripheral and non-peripheral regions. Implications for policy, teacher professional development, and further research on AI-supported pedagogy in disadvantaged contexts are discussed.

Keywords: Competence, digital, elementary, training.

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INTRODUCTION

Rapid digital transformation is reshaping how knowledge is produced, accessed, and shared, creating new expectations for teachers' professional roles and competencies in schools globally.

In educational systems, digital technologies and artificial intelligence (AI) are increasingly embedded in curriculum design, instructional delivery, assessment practices, and school management, requiring teachers to move beyond basic operational skills toward more sophisticated pedagogical uses of technology. As a result, digital competence has emerged as a core dimension of teacher professionalism, influencing both instructional quality and students' preparedness for participation in a digitally mediated society (Ghomi & Redecker, 2019)

In Indonesia, the challenge of developing teachers' digital competence is particularly acute in frontier, outermost, and underdeveloped (3T) regions, which are formally designated to highlight persistent structural disadvantages and prioritize targeted developmental interventions.

3T regions are characterized by difficult geography, limited transportation and communication infrastructure, and lower socioeconomic indicators, all of which contribute to systemic educational inequality (Ebabuye & Asgedom, 2023).

Schools in these areas often struggle with a shortage of qualified teachers, inadequate learning facilities, and limited access to stable Internet connectivity and up-to-date digital devices. These constraints make it more difficult for teachers to participate in continuous professional development and meaningfully integrate digital technologies into classroom practice.

The COVID-19 pandemic magnified pre-existing educational disparities by forcing a rapid shift toward remote and hybrid learning models that rely heavily on digital platforms.

While urban schools with better connectivity were able to experiment with online learning management systems and digital resources, many schools in 3T regions faced severe learning loss due to limited access to devices, connectivity, and teacher preparedness for technology-supported pedagogy (Wike & Elenwo, 2025).

In response, universities, NGOs, and government programs have initiated various support schemes, including community learning spaces and targeted mentoring for students and teachers in 3T regions however,the digital competence gap remains substantial.

To conceptualize teacher digital competence, this study draws on the European Digital Competence Framework for Educators (DigCompEdu), which articulates 22 competences organized into six areas: (1) professional engagement, (2) digital resources, (3) teaching and learning, (4) assessment, (5) empowering learners, and (6) facilitating learners' digital competence.

DigCompEdu emphasizes that digital competence is not limited to technical skills but concerns how educators leverage digital tools to enrich pedagogy, collaborate professionally, and empower students to become critical, responsible digital citizens. The framework also recognizes progressive proficiency levels, from novice (A1) to leader (C2), providing a developmental perspective on teacher growth (Momdjian et al., 2025).

The DigCompEdu framework aligns with Technological Pedagogical Content Knowledge (TPACK), which posits that effective technology integration depends on the dynamic interplay among teachers' content, pedagogical, and technological knowledge.

In 3T contexts, where material resources and connectivity are constrained, the ability to design low-bandwidth, contextually relevant digital instruction is crucial. Teachers must be able to select, adapt, and create learning resources that are not only technically accessible but also culturally and linguistically aligned with local learners' needs.

Simultaneously, AI—especially generative AI based on large language models—has introduced new possibilities for instructional design. Recent professional development programs and workshops in various countries have started to focus on AI for instructional design, emphasizing how AI tools can support educators in generating learning objectives, content outlines, assessment items, feedback, and multimedia resources.

These initiatives typically train educators to write effective prompts, critically evaluate AI-generated outputs, and integrate AI support into existing workflows. The promise of AI lies in its potential to reduce teachers' preparation time, inspire more varied instructional strategies, and support the differentiation and personalization of learning tasks (Rinla et al., 2025).

However, the pedagogical value of AI depends heavily on teachers' digital competence, critical thinking skills, and ethical awareness. Without adequate training, teachers may underutilize AI tools or rely on them in ways that undermine learning objectives, reinforce bias, or compromise academic integrity.

In 3T regions, where teachers already face multiple constraints, AI-based professional development must be carefully designed to be accessible, context-sensitive, and aligned with local curriculum priorities. It cannot assume uninterrupted connectivity, unlimited access to high-end devices, or prior familiarity with advanced digital tools.

Despite the growing interest in AI for education and a large body of literature on digital competence frameworks, empirical studies quantitatively examininge AI-based instructional design training for teachers in disadvantaged or peripheral regions remain limited. Existing research on education in Indonesia's 3T areas has tended to focus on macro-level policy, qualitative descriptions of inequality, and strategies for improving the quality of education through infrastructure development, teacher deployment and community participation.

While these perspectives are crucial, there is a need for micro-level, teacher-focused interventions that explicitly address digital pedagogy and examine their impact using robust empirical designs.

This study addresses this gap by designing and implementing an AI-based instructional design training program tailored to elementary school teachers in the 3T regions. Grounded in DigCompEdu and TPACK, the program introduces teachers to generative AI tools that can assist with lesson planning, learning resource design, and formative assessment while emphasizing critical evaluation, alignment with curricular standards, and ethical considerations. Training adopts low-bandwidth strategies, including asynchronous materials that can be downloaded for offline use and synchronous sessions scheduled at times that accommodate local constraints.

The main objective of thise study was to investigate whether participation in this AI-based training program leads to measurable improvements in teachers' self-reported digital competence across the six DigCompEdu areas. Thise study was guided by the following questions:

- To what extent does AI-based instructional design training improve the overall digital competence of elementary school teachers in the 3T regions?
- Which areas of digital competence (professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence) showed the greatest gains following the training?
- How do teacher characteristics such as teaching experience and prior exposure to digital tools relate to gains in digital competence?

By addressing these questions, thise study aims to provide evidence of the potential of AI-based professional development to support teachers in challenging contexts, contribute to the operationalization of digital competence frameworks in practice, and inform future policy and program design for 3T regions

METHOD

Thise study employed a quantitative one-group pretest–posttest design to assess changes in teachers' digital competence following participation in an AI-based instructional design training program. This design was selected to capture within-subject changes over time in contexts where it is difficult to establish experimental control groups due to the logistical and ethical constraints commonly encountered in 3T regions (Creswell, 2021).

Participants and Setting

The participants were 120 elementary school teachers from several officially designated 3T districts in Indonesia. The districts were selected in collaboration with local education authorities to ensure the representation of schools characterized by geographical remoteness, limited infrastructure, and constrained access to professional development opportunities.

Cluster sampling was used at the district level, followed by the purposive selection of schools that had at least minimal access to digital devices (e.g., shared computers or smartphones) and intermittent internet connectivity needed for hybrid training delivery.

The sample comprised teachers with diverse backgrounds in terms of age, teaching experience, and prior exposure to digital technology. Many participants taught multiple grade levels and subjects due to teacher shortages in their schools, reflecting typical staffing patterns in 3T regions (Sugiyono, 2019).

Participation in the training was voluntary but endorsed by local education offices, and all the participants provided informed consent.

Intervention: AI-Based Instructional Design Training

The intervention was a structured AI-based instructional design training program with a total duration of 24 hours delivered over four weeks. The program combined synchronous online sessions (via low-bandwidth video conferencing and messaging

applications) with asynchronous learning materials that could be downloaded and accessed offline. The program design was informed by existing AI-for-instructional-design workshops and courses that emphasized prompt engineering, critical analysis of AI outputs, and integration of AI into instructional design workflows.

The training comprised four thematic modules:

Foundations of digital pedagogy and DigCompEdu: Introduction to the six DigCompEdu areas and reflection on current practices; overview of TPACK and its relevance in 3T contexts.

Introduction to AI tools for teachers: Basic concepts of generative AI, exploration of one or two accessible large language model platforms, and hands-on activities in writing prompts for lesson ideas, explanations, and examples.

AI-supported instructional design: Using AI to draft lesson plans, create differentiated activities, generate assessment items, and adapt resources for low-bandwidth and culturally relevant contexts.

Ethical, critical, and sustainable use of AI: Discussion of academic integrity, bias, data privacy, and strategies for maintaining teacher agency and critical judgement when using AI tools.

Facilitators encouraged participants to experiment with AI tools using locally relevant curriculum topics and collaboratively review and revise AI-generated outputs. Between sessions, the teachers completed practical assignments such as redesigning an upcoming lesson with AI support and reflecting on the experience.

Instruments

Teacher digital competence was measured using a questionnaire adapted from the DigCompEdu self-assessment instruments developed in prior studies.

The adapted instrument contained items for each of the six DigCompEdu areas, with 4–5 items per area, resulting in a total of 26 items. Items were rated on a four-point Likert scale ranging from 1 (novice/basic) to 4 (advanced/expert), consistent with the DigCompEdu proficiency descriptions.

The adaptation process involved translating and contextualizing items to the Indonesian primary education context and 3T realities, including examples of low-bandwidth digital practices and tools available locally. Content validity was examined by a panel of experts in educational technology and professional teacher development. A pilot test with a small group of teachers outside the study sample indicated satisfactory internal consistency, with an overall Cronbach's alpha above 0.90 and subscale alphas above 0.80.

The questionnaire was administered twice: one week before the start of training (pretest) and one week after the final training session (posttest). In addition, a short demographic section collected data on teachers' gender, age, teaching experience, subject specialization, prior participation in digital training, and frequency of technology use in teaching settings.

Data Collection Procedures

Given the connectivity constraints, data collection combined online and offline methods. Where possible, teachers completed the questionnaire online using a mobile-

friendly survey form. In locations with limited Internet access, printed questionnaires were distributed through local coordinators and later digitized. The same approach was used for pre and post test administration to maximize participation and minimize attrition.

Throughout the intervention, the facilitators maintained communication with the participants through messaging groups, providing reminders and technical support. Local coordinators helped troubleshoot connectivity issues and facilitated access to shared devices in schools and community centers.

Data Analysis

The data were screened for completeness, and cases with substantial missing responses were excluded from the inferential analyses. Descriptive statistics (means and standard deviations) were computed for the overall digital competence scores and for each DigCompEdu area in the pre and post tests. To test the first and second hypotheses, paired-sample t-tests were conducted comparing pre and post test scores overall and by area. Effect sizes were calculated using Cohen's d to estimate the magnitude of the change.

Exploratory analyses examined the associations between teacher characteristics (e.g., teaching experience and prior digital training) and gains in digital competence using correlation and group comparisons. These analyses provided additional insight into which subgroups benefited most from the training, al though the study was not powered for complex multivariate modeling.

All analyses were conducted using standard statistical software. Statistical significance was evaluated at the 0.05 level, with particular attention to the practical significance of effect sizes given the professional development context.

RESULTS AND DISCUSSION

A total of 120 teachers completed the pre and post test questionnaires. Table 1 summarizes the key demographic characteristics.

Table 1. Participant Characteristics (N = 120)

Variable	Category	n	%
Gender	Female	84	70.0
	Male	36	30.0
Age	≤ 30 years	18	15.0
	31–40 years	49	40.8
	41–50 years	37	30.8
	≥ 51 years	16	13.3
Teaching experience	≤ 5 years	22	18.3

Variable	Category	n	%
	6–10 years	38	31.7
	11–20 years	42	35.0
	> 20 years	18	15.0
Prior digital training	None	73	60.8
	1 short course	32	26.7
	≥ 2 courses	15	12.5

The sample reflected a predominantly female teaching workforce with a wide range of teaching experiences. Notably, more than half of the participants reported no prior formal digital training, underscoring the need for targeted professional development in the 3T regions.

Pretest and Posttest Digital Competence Scores

The descriptive statistics for the pre and post test mean scores across the six DigCompEdu areas are presented in Table 2. These scores are based on a four-point Likert scale, with higher scores indicating higher self-reported competence.

Table 2. Pretest and Posttest Mean Scores by DigCompEdu Area (N = 120)

Area (Dimension)	Pretest Mean	Posttest Mean
Professional engagement	2.4	3.6
Digital resources	2.1	3.5
Teaching and learning	2.3	3.7
Assessment	2.0	3.4
Empowering learners	2.2	3.5
Facilitating learners' digital competence	2.1	3.6

The results showed substantial increases in the mean scores across all areas. At the pretest, the mean scores ranged between 2.0 and 2.4, suggesting that teachers perceived themselves at approximately basic to intermediate levels of digital competence. After the training, the mean scores increased to between 3.4 and 3.7, indicating that many teachers moved toward advanced levels across the DigCompEdu areas.

The largest gains were observed in the "Teaching and learning" and "Facilitating learners' digital competence" areas, reflecting the training's focus on designing AI-supported learning activities and guiding students in using digital tools critically and creatively. Improvements in "Assessment" and "Digital resources" also indicate that

teachers became more confident in using AI and digital tools to construct assessment tasks and curate or create digital learning materials for their students.

The aggregated means used in Table 2 are also visualized in a grouped bar chart showing the pre and post test mean scores for each DigCompEdu area.

Inferential Analysis

Paired-sample t-tests were conducted to examine the statistical significance of the changes in the digital competence scores. Table 3 summarizes the mean differences, t-values, significance levels, and effect sizes (Cohen's d) for each DigCompEdu area and the overall composite score.

Table 3. Paired-Sample t-Test Results for Digital Competence Scores (N = 120)

Area	Mean Difference (Post – Pre)	t(df = 119)	p-value	Cohen's d
Professional engagement	1.2	18.5	< 0.001	1.69
Digital resources	1.4	21.2	< 0.001	1.94
Teaching and learning	1.4	22.0	< 0.001	2.01
Assessment	1.4	20.8	< 0.001	1.90
Empowering learners	1.3	19.7	< 0.001	1.80
Facilitating learners' digital competence	1.5	22.3	< 0.001	2.04
Overall composite	1.37	25.1	< 0.001	2.29

All mean differences were positive and statistically significant at the 0.001 level, indicating robust improvements across the dimensions. Effect sizes ranged from 1.69 to 2.04 for individual areas and 2.29 for the overall composite score, representing very large effects in educational research. These findings strongly support the first hypothesis that AI-based instructional design training significantly increases teachers' digital competence.

Exploratory analyses examined the relationships between teacher characteristics and digital competence gains. Teachers with no prior digital training tended to show slightly larger gains in several DigCompEdu areas than those with prior training, although the differences were not always statistically significant. This pattern suggests a "catch-up" effect whereby the training particularly benefited teachers starting from lower initial competence levels.

Teaching experience showed a modest, non linear relationship with gains. Early career teachers (≤ 5 years) and mid-career teachers (6–10 years) reported somewhat larger gains than those with more than 20 years of experience, possibly reflecting greater openness to experimenting with new tools among younger cohorts of teachers. However, even the most experienced teachers demonstrated significant improvements,

indicating that AI-based instructional design training can be valuable at all career stages.

The frequency of technology use in teaching at the pretest was positively correlated with pretest digital competence scores but negatively correlated with the magnitude of gains, consistent with the idea that teachers who were already more digitally active had less room for improvement. Nonetheless, they still reported meaningful increases in specific areas such as "Assessment" and "Facilitating learners' digital competence," which were heavily emphasized in the training.

The descriptive statistics underlying the visualization of the mean scores form part of a dataset stored in a separate artifact.

Discussion

The findings of this study demonstrate that a relatively short, targeted AI-based instructional design training program can substantially strengthen the digital competence of elementary school teachers in Indonesia's 3T regions. Large, statistically significant gains were observed across all six DigCompEdu areas, with particularly marked improvements in "Teaching and learning" and "Facilitating learners' digital competence." These results align with the conceptualization of digital competence as a multidimensional construct and suggest that AI-supported training can influence not only technical skills but also the pedagogical and learner-centered dimensions of practice.

The strong gains in "Teaching and learning" may be attributed to the training's emphasis on using AI tools to support lesson planning, activity design and differentiation. By engaging teachers in hands-on tasks where they generate lesson ideas, adapt content for local contexts, and collaboratively critique AI outputs, the program likely increases both confidence and practical strategies for integrating digital tools into daily instruction (Eryuni Ramdhayani Eryuni et al., 2025).

The focus on low-bandwidth and offline-friendly designs may also have enhanced teachers' sense of feasibility, countering the common perception that digital innovation is impossible in resource-poor environments.

Improvements in "Facilitating learners' digital competence" indicate that teachers moved beyond using technology solely as a delivery tool to viewing students as active digital learners who require guidance in information literacy, critical thinking, and responsible technology use.

This shift is particularly significant in 3T regions where students' exposure to digital technologies may be sporadic. This suggests that AI-supported training can encourage teachers to see digital competence as a shared developmental goal rather than an individual technical skill set (Vorobel et al., 2021).

The observed gains in "Assessment" and "Digital resources" also align with the training modules that explicitly covered AI-supported test item generation, formative feedback, and resource curation. By learning how to use AI to generate question pools, design rubrics, or adapt open educational resources, teachers are likely to have expanded their repertoire of assessment strategies and resource creation techniques.

Importantly, the training emphasized the critical evaluation of AI outputs and alignment with curricular standards, helping teachers maintain professional judgement rather than deferring to automated suggestions (Yafie et al., 2024).

From a 3T policy perspective, the results provide evidence that carefully designed digital professional development can succeed even under significant infrastructural constraints. Many teachers in the sample had no prior formal digital training and worked in schools with limited connectivity, yet they still achieved substantial competence gains. This suggests that while serious, structural barriers do not preclude meaningful teacher development when programs are adapted to local conditions, employ hybrid delivery models, and provide strong facilitation and local coordination.

However, it is important to situate these findings within the broader dynamics of educational inequality in the 3T regions. Qualitative research has highlighted that educational experiences in these areas are shaped by power relations, identity, and struggles for recognition, not merely by infrastructure and training (Omuya et al., 2025).

Therefore, AI-based professional development must be integrated into longer-term, community-engaged strategies that address structural inequities and foster local agency. Teachers' enhanced digital competence can contribute to these efforts, but cannot substitute for investments in infrastructure, school facilities, and broader social support.

The exploratory analyses provide additional insights. The slightly larger gains among teachers with no prior digital training and among early- and mid-career teachers suggest that AI-based programs may be particularly effective in raising the competence of those previously underserved by professional development opportunities. At the same time, the significant gains across all experience levels underscore that AI-supported training is not only for "digital natives" but can also be valuable to veteran teachers.

These findings are consistent with emerging international experiences in AI-focused professional development, where educators across age and experience groups report increased efficiency, creativity, and reflective practice when integrating AI tools into their instructional design.

The present study extends this literature by demonstrating similar patterns in a highly constrained peripheral context (Dwyer et al., 2026).

Implications for Practice and Policy

This study has several practical implications. First, educational authorities and teacher education institutions should consider integrating AI-based instructional design modules into broader digital competence frameworks and professional development offerings. Aligning training content with recognized frameworks such as DigCompEdu can provide a coherent structure for teacher growth and facilitate the monitoring of progress over time.

Second, professional development in 3T regions should continue to adopt hybrid and flexible delivery models that combine synchronous interactions with asynchronous, offline-accessible materials. Partnerships with local coordinators, community learning centers, and higher education institutions can help overcome connectivity and device limitations, as evidenced by prior learning assistance initiatives in 3T areas.

Third, AI-based training should incorporate explicit attention to ethicals issues, data privacy, and bias. In contexts where teachers may rely heavily on a limited number of AI tools or platforms, it is crucial to ensure that educators understand the limitations, potential harms, and responsibilities associated with AI use.

This includes discussing how AI-generated content should be adapted to reflect local cultural values, languages, and student realities.

Fourth, sustaining gains in digital competence will require ongoing support, including communities of practice in which teachers can share AI-supported lesson designs, troubleshoot challenges, and mentor peers. Such peer networks can help mitigate the isolation often experienced by teachers in the 3T regions and foster a culture of collaborative innovation.

Limitations and Directions for Future Research

Thise study has several limitations. The one-group pretest–posttest design does not allow for strong causal inference, as it lacks a control group that did not receive training. Although the magnitude and consistency of the gains provide compelling evidence of training effectiveness, other factors such as concurrent initiatives or temporal effects can not be fully ruled out.

Reliance on self-reported digital competence is another limitation. Self-assessment data may be influenced by social desirability bias, varying interpretations of competence descriptors, or changes in self-awareness triggered by training. Future research should incorporate performance-based assessments, classroom observations, and analyss of AI-supported instructional artifacts to triangulate self-reported data.

Moreover, thise study focused on short-term outcomes measured shortly after the completion of training. Longer-term follow-up is needed to examine the sustainability of gains, the extent to which teachers continue to use AI tools in their practice, and their impact on student learning outcomes, particularly in relation to digital literacy and higher-order thinking skills.

Finally, the study was conducted in a specific set of 3T districts, and the findings may not be generalizable to all 3T contexts or to non-3T regions. Comparative studies examininge AI-based instructional design training across diverse Indonesian regions or countries with similar peripheral educational challenges would help clarify the role of contextual factors

CONCLUSION

This study provides empirical evidence that AI-based instructional design training can substantially enhance the digital competence of elementary school teachers in Indonesia's 3T regions. Grounded in the DigCompEdu framework and adapted to the realities of resource-constrained peripheral contexts, the training led to large and statistically significant gains across all six areas of digital competence. Teachers reported greater confidence in using digital resources, designing technology-enhanced learning activities, implementing digital assessment strategies, empowering learners, and facilitating students' digital competence. The findings underscore that targeted, contextually sensitive professional development can help narrow digital competence gaps between teachers in 3T and non-3T regions, even in the presence of infrastructure limitations. Simultaneously, integrating AI into teacher professional development raises important questions about ethics, sustainability, and equity that require ongoing

attention. Future work should explore long-term outcomes, incorporate more diverse measures of competence, and link teacher development to broader efforts to transform educational opportunities in 3T communities..

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Ethical Compliance

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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