JPPM
Jurnal Penelitian dan Pengabdian kepada Masyarakat

Volume 1 Issue 4 | NOVEMBER 2025
e-ISSN: 3090-6679
https://ejournal.selectaedukasi.id/index.php/jppm

Reconstructing Teacher Technopedagogical Competence through Generative AI–Supported Service-Learning: Evidence from a Participatory Action Research in Rural Indonesia

https://doi.org/xxxxxx

Yosepus A. Hallatu[1*], Dewilna Helmi[1], Asep Asep[1], Herwic K. Pinoa[1], Luis Matital[1]
[1]Universitas Pattimura, Jalan Ir M. Putuhena, Ambon 97233, Indonesia

Abstract

This study aims to reconstruct teachers' technopedagogical competence through the integration of generative artificial intelligence (AI) within a participatory and contextualized service-learning framework in rural Indonesia. The research addresses critical gaps in digital education transformation, including limited teacher competence, underutilization of generative AI, and the lack of context-responsive professional development. Employing a Participatory Action Research (PAR) approach with an embedded mixed-methods design, the study involved 20 junior secondary school teachers in a disadvantaged (3T) region. The research stages included needs diagnosis, AI-based training design, hands-on implementation (prompt engineering and instructional material development), observation through pre- and post-assessment, and collaborative reflection. Data were collected through competency tests, in-depth interviews, participatory observation, and document analysis, and analyzed using quantitative (gain analysis) and qualitative (thematic analysis) techniques with triangulation. The findings reveal significant improvements in teachers' understanding of generative AI, prompt design skills, and the ability to develop contextualized digital teaching materials, particularly in coding education. Teachers also demonstrated a shift from technology users to adaptive co-creators of learning. The study introduces an AI-Supported Technopedagogical Reconstruction Model, integrating generative AI, TPACK, service-learning, and PAR. The results highlight the effectiveness of participatory AI-based approaches in enhancing teacher competence and fostering sustainable educational impact in developing contexts.

Keywords: *Artificial Intelligence, Community Engagement, Service-Learning, Teacher Competence, Technopedagogy*

Article Info:

Correspondence E-Mail:
yoseppushallatu@gmail.com

Received manuscript: *15/08/2025*
Final revision: *08/09/2025*
Approved: *19/10/2025*
Online Access: *30/11/2025*
Published: *30/11/2025*

How to cite: Hallatu, Y. A., Helmi, D., Asep, A., Pinoa, H. K., & Matital, L. (2025). Reconstructing Teacher Technopedagogical Competence through Generative AI–Supported Service-Learning: Evidence from a Participatory Action Research in Rural Indonesia. *Jurnal Penelitian dan Pengabdian kepada Masyarakat (JPPM), 1*(4), 367-391. *https://doi.org/xxxxxx*

Publisher: *PT. Sarana Mandiri Investama*
RT 07 RW 03 Desa Salamrejo Kec. Karangan , Kab. Trenggalek, Provinsi Jawa Timur, Indonesia
E-mail:
selectaedukasigrup.journal@gmail.com

INTRODUCTION

The rapid acceleration of digital transformation in education has been profoundly shaped by the emergence of generative artificial intelligence (AI), which offers unprecedented opportunities for personalized learning, automated content creation, and adaptive pedagogical design (Ivanov et al., 2024; Zaluchu et al., 2025). Yet, the diffusion of these innovations remains uneven, particularly in rural and underdeveloped regions where structural limitations intersect with pedagogical challenges. In the Indonesian context,

especially in frontier, outermost, and disadvantaged (3T) areas, teachers continue to face significant barriers in integrating digital technologies into meaningful learning practices. Empirical evidence indicates that disparities in infrastructure, professional development access, and digital literacy contribute to persistent gaps in educational quality between urban and rural settings (Habibi et al., 2024; Mashami et al., 2025; Yudiani et al., 2025). These conditions are further exacerbated by the rapid evolution of AI technologies, which outpace the readiness of teachers to adopt them effectively in classroom contexts.

At the core of this issue lies the concept of technopedagogical competence, often framed within the Technological Pedagogical Content Knowledge (TPACK) model, which emphasizes the dynamic interplay between technology, pedagogy, and subject matter knowledge (Margono et al., 2024; S. Rahmawati et al., 2025). While TPACK has been widely recognized as a critical framework for 21st-century teaching, studies consistently show that many teachers, particularly in developing regions, struggle to operationalize this knowledge in practice (Arnab et al., 2025; Purnamasari et al., 2025; Waluyo & Kusumastuti, 2024). In Indonesia, recent findings reveal that teachers' technological integration remains largely superficial, often limited to basic digital tools without deeper pedagogical transformation (Ismail et al., 2025; Yunaini et al., 2025). The introduction of generative AI, such as large language models and AI-driven content generators, has the potential to bridge this gap by enabling teachers to design more interactive and contextually relevant learning materials. However, without adequate support and training, these technologies risk becoming underutilized or misapplied.

A growing body of literature has explored the role of AI in education, highlighting its capacity to enhance learning outcomes, support teacher productivity, and facilitate differentiated instruction (Fahrurrozi, 2025; Nurhasanah et al., 2025; Syahruddin et al., 2025). Generative AI, in particular, has gained attention for its ability to produce instructional content, generate code, and simulate problem-solving scenarios (Gusweni et al., 2025; Nurtanto et al., 2025; Taufik et al., 2025). Despite these promising developments, most existing studies are situated in technologically advanced contexts, where infrastructure and digital readiness are already well established. Consequently, there is limited empirical evidence on how generative AI can be meaningfully integrated into teaching practices in resource-constrained environments. Moreover, concerns have been raised regarding the ethical, pedagogical, and contextual implications of AI use, particularly in settings where teachers may lack critical digital competencies (Abusamra et al., 2025; Septiana et al., 2025; Yarmi, 2025).

Parallel to these technological advancements, the pedagogical approach of service-learning has gained recognition as a means of connecting academic knowledge with real-world community needs. Service-learning emphasizes experiential learning, social responsibility, and reciprocal engagement between educators and communities (Maksum et al., 2025; Marini et al., 2025). In educational research, this approach has been shown to enhance teacher reflection, foster contextual understanding, and promote socially responsive

pedagogy (Egana-delSol et al., 2022; Sandanayaka et al., 2025; Tlais et al., 2025). However, its integration with emerging technologies such as AI remains largely unexplored. Similarly, Participatory Action Research (PAR) has been widely adopted as a collaborative methodology that positions participants as co-researchers, enabling iterative cycles of reflection and action (Filippi et al., 2023b; Muawanah et al., 2024). PAR has proven effective in educational settings for empowering teachers and fostering sustainable change, particularly in marginalized communities (Arifin et al., 2024; Tanchangya et al., 2025). Yet, the intersection of PAR, service-learning, and AI-supported pedagogical innovation remains an underdeveloped area of inquiry.

Several studies have attempted to address aspects of teacher digital competence through professional development programs. For instance, Abazoglu & Alhourani (2025) and Hasan et al. (2025) emphasize the importance of contextualized training that aligns with teachers' classroom realities, while E. Rahmawati et al. (2025) and Shahat et al. (2025) highlight the need for collaborative learning environments that support continuous professional growth. In the Indonesian setting, initiatives aimed at improving digital literacy have shown mixed results, often constrained by top-down implementation models that fail to engage teachers as active agents of change (Acosta-Enriquez et al., 2025; Musyaffi et al., 2024; Waluyo et al., 2025). Furthermore, research on coding education in schools suggests that teachers often lack the confidence and resources to develop computational thinking skills among students (Afdawaiza et al., 2025; Wibowo et al., 2023). This gap becomes more pronounced in rural areas, where access to training and technological tools is limited.

Recent discussions in the field have begun to explore the potential of prompt engineering as a new form of digital literacy, particularly in the context of generative AI (Alkamel & Alwagieh, 2024; Yadav et al., 2024; Zhou et al., 2024). Prompt engineering involves the strategic formulation of inputs to guide AI systems in generating desired outputs, thereby requiring both technical understanding and pedagogical insight. For teachers, this skill represents an opportunity to co-create learning materials with AI, rather than passively consuming pre-designed resources. However, empirical studies examining how teachers develop and apply prompt engineering skills in authentic educational contexts remain scarce. This limitation points to a broader need for research that not only examines technological adoption but also redefines the role of teachers as active designers of AI-enhanced learning environments.

Against this backdrop, a closer reading of the existing scholarship suggests that while each of these domains, AI in education, TPACK, service-learning, and participatory methodologies, has evolved considerably, their convergence has yet to be fully realized, particularly in contexts where educational inequities are most pronounced. The absence of integrative frameworks that simultaneously address technological innovation, pedagogical transformation, and community engagement leaves a critical space for rethinking how teacher competence can be reconstructed in a holistic and context-sensitive manner.

In response to these challenges, this study advances an approach that brings together generative AI, service-learning, and Participatory Action Research within the TPACK framework to reconstruct teachers' technopedagogical competence in rural Indonesia. Rather than positioning teachers as passive recipients of technological training, this research situates them as co-designers, co-implementers, and evaluators of AI-supported learning practices. Through iterative cycles of action and reflection, teachers engage in hands-on experiences with AI tools, develop prompt engineering skills, and create contextually relevant teaching materials, particularly in the domain of coding education. This integrative approach not only addresses the immediate need for practical and scalable teacher training models but also contributes to a broader reconfiguration of teacher identity in the age of AI.

Accordingly, the purpose of this study is to examine how a participatory, AI-supported service-learning model can enhance teachers' technopedagogical competence, to analyze the effectiveness of Participatory Action Research in facilitating this transformation, and to develop a contextually grounded training model that can be adapted and scaled across similar educational settings. By foregrounding the lived experiences of teachers in rural communities and embedding technological innovation within socially meaningful practices, this research seeks to contribute to the ongoing discourse on equitable and sustainable educational transformation.

RESEARCH METHOD

This study adopts a qualitative-oriented Participatory Action Research (PAR) design, enriched with embedded quantitative elements, to capture both the depth of teachers' lived experiences and measurable shifts in their technopedagogical competence. A qualitative approach is particularly appropriate given the study's focus on understanding how teachers interpret, negotiate, and reconstruct their professional practices in response to generative AI integration. Rather than merely assessing outcomes, the research seeks to explore processes of transformation, reflection, and co-creation, which are inherently contextual and socially constructed (Ciff et al., 2024; Tseng et al., 2021; J. Wang & Li, 2024). PAR further strengthens this approach by positioning participants not as passive subjects but as active collaborators who engage in iterative cycles of planning, action, observation, and reflection (Cheng et al., 2024; Wulandhari et al., 2021). This methodological choice aligns with the study's commitment to empowerment and sustainability, especially in underserved educational contexts.

The research was conducted in a rural district in Indonesia, specifically selected due to its representation of 3T (frontier, outermost, and disadvantaged) characteristics, where disparities in digital access and teacher professional development are most pronounced. This location provides a critical lens for examining how global technological innovations, such as generative AI, intersect with local educational realities. The selection was also informed by preliminary observations and regional education reports indicating limited exposure to AI-based tools and a strong need for contextually relevant training programs. By situating the

study in this environment, the research not only addresses a significant empirical gap but also ensures that the findings are grounded in real-world challenges faced by teachers in developing regions.

The participants consisted of 20 junior secondary school teachers specializing in science and technology-related subjects. These individuals were purposively selected based on their teaching roles, willingness to engage in a collaborative research process, and limited prior experience with AI technologies. The inclusion of this group reflects the study's focus on educators who are directly involved in delivering content that can benefit from computational and digital enhancement, particularly in coding-related learning. Their participation as co-researchers is central to the PAR framework, as they contribute to the design, implementation, and evaluation of the intervention. This collaborative involvement fosters a sense of ownership and increases the likelihood of sustainable pedagogical change (Ahmad et al., 2025; Ma & Zhang, 2023).

Data collection was carried out through multiple, interconnected methods to ensure a comprehensive understanding of the phenomenon. Pre- and post-intervention assessments were administered to capture changes in teachers' technopedagogical competence, particularly in their understanding of generative AI and ability to construct effective prompts. These quantitative measures were complemented by in-depth interviews, which provided nuanced insights into teachers' perceptions, challenges, and evolving practices. Participatory observations were conducted throughout the training sessions and classroom implementations, allowing the researcher to document real-time interactions, adaptations, and collaborative dynamics. In addition, document analysis was employed to examine the instructional materials produced by teachers, such as lesson plans, worksheets, and AI-generated content, offering tangible evidence of learning outcomes and pedagogical shifts.

The use of these diverse methods is grounded in the principle of methodological triangulation, which enhances the credibility and validity of qualitative research (Huo et al., 2024; Maroufkhani et al., 2022; L. Zhang et al., 2024). Triangulation was conducted by cross-verifying data from different sources and methods, ensuring that emerging findings were consistently supported across interviews, observations, assessments, and artifacts. Furthermore, member checking was conducted during the reflection phase of each PAR cycle, where participants reviewed and validated the interpretations of their experiences. This iterative validation process not only strengthens the trustworthiness of the data but also reinforces the participatory ethos of the study.

Data analysis followed a convergent approach, integrating quantitative and qualitative findings to generate a holistic interpretation. Quantitative data were analyzed using gain scores to identify patterns of improvement, while qualitative data underwent thematic analysis to uncover recurring themes related to competence development, agency, and contextual adaptation (Challco et al., 2024; C. Wang et al., 2024).

RESULTS AND DISCUSSION

Initial Conditions: Diagnosing Teachers' Technopedagogical Gaps in Rural Contexts

The initial phase of this study sought to carefully diagnose the existing condition of teachers' technopedagogical competence prior to the intervention, drawing on multiple sources of evidence including pre-test results, in-depth interviews, and participatory classroom observations. The findings reveal a layered and nuanced picture of technological engagement in rural educational contexts, where access alone does not translate into meaningful integration. Quantitatively, the pre-test results indicated that the majority of participating teachers demonstrated low baseline competence in areas related to generative AI, with average scores clustering in the lower performance band, particularly in items measuring conceptual understanding and practical application. Most participants were unfamiliar with the concept of generative AI beyond surface-level exposure, and none reported prior experience in using AI tools for instructional design. This lack of familiarity extended to prompt construction, where teachers expressed uncertainty about how to formulate effective inputs to guide AI-generated outputs.

These quantitative patterns were further illuminated by qualitative insights. Interviews revealed that teachers' engagement with technology remained largely instrumental and administrative rather than pedagogical. As one participant (T.A.) noted, "We use technology mostly for presentations or reporting, not for designing learning itself." This statement reflects a broader trend observed across participants, where digital tools are perceived as supplementary rather than transformative. Another teacher (R.S.) shared that while they had heard about AI through social media, they "did not know how it could be used in teaching, especially for subjects like coding." Such reflections underscore a critical gap between awareness and actionable knowledge, highlighting that exposure to technology does not necessarily equate to competence.

Classroom observations further reinforced this pattern, showing that teaching practices were still predominantly teacher-centered, with limited opportunities for student interaction, problem-solving, or integration of digital resources. Instructional delivery relied heavily on textbooks and static materials, and even when digital devices were available, their use was confined to basic functions such as displaying slides. There was little evidence of alignment between technological tools and pedagogical strategies, suggesting that the integration of technology into teaching remained superficial. This aligns with previous findings that in many developing contexts, technology adoption often occurs without corresponding shifts in pedagogical orientation (Filippi et al., 2023a; Lai & Li, 2024; Priharsari et al., 2023).

From a conceptual standpoint, these findings can be understood through the lens of digital inequality in education, which extends beyond issues of access to encompass disparities in skills, usage, and outcomes (David et al., 2025; Ullah & Begum, 2025; Xu et al., 2024). In this study, while some level of technological infrastructure was present, the deeper layers of digital competence, particularly those related to critical, creative, and pedagogical

uses of technology, were largely underdeveloped. Teachers were not only constrained by limited training opportunities but also by the absence of contextualized support systems that could bridge global technological innovations with local educational needs. This reflects what Fang et al. (2024) and Yáñez-Valdés et al. (2023) describes as the "second-level digital divide," where inequalities manifest in how technology is used and for what purposes.

The TPACK framework provides a useful analytical lens to further interpret these conditions. Although widely recognized as a foundational model for integrating technology in education (Awais et al., 2023), its practical internalization among the participating teachers appeared limited. Most participants demonstrated isolated knowledge domains, content knowledge and basic pedagogical knowledge, without the integrative capacity that defines technopedagogical competence. For instance, while teachers were confident in delivering subject matter, they struggled to identify how digital tools, particularly AI-based ones, could enhance conceptual understanding or student engagement. This disconnect suggests that TPACK, as a conceptual framework, has not been effectively translated into actionable teaching practices in this context.

Moreover, the absence of prior exposure to participatory and reflective professional development models further contributed to this gap. Teachers reported that most training programs they had attended were top-down in nature, focusing on theoretical instruction rather than hands-on application. As one informant (M.L.) explained, "Usually we are told what to do, but not given the chance to try or adapt it to our classroom." This lack of agency not only limits skill acquisition but also hinders the development of reflective practice, which is essential for sustained professional growth (Büyüközkan & Güler, 2025; Uddin et al., 2023; H. Zhang et al., 2024). In contrast, the PAR approach adopted in this study was intentionally designed to address this limitation by involving teachers as active participants in the learning process.

Transformative Learning through AI-Supported Service-Learning Interventions

The intervention phase of this study unfolded as a carefully structured yet adaptive learning process, grounded in the principles of service-learning and operationalized through iterative cycles of Participatory Action Research (PAR). Rather than positioning training as a one-directional transfer of knowledge, the program was designed as a collaborative space where teachers actively engaged with generative artificial intelligence (AI) tools in ways that were directly connected to their classroom realities. This approach reflects a deliberate shift from conventional professional development models toward experiential, context-responsive learning environments, where knowledge is constructed through practice, dialogue, and reflection. The integration of generative AI within this framework was not treated as a technical add-on, but as a mediating tool that enabled teachers to rethink how learning materials are designed, adapted, and contextualized.

The intervention began with a co-design phase, in which teachers and researchers collaboratively identified learning needs and defined practical goals for the training. This initial engagement proved crucial in fostering a sense of ownership among participants, as

they were invited to articulate their challenges and expectations. As one participant (S.R.) reflected, “This is the first time we are asked what we actually need before the training starts.” Such early involvement aligns with the participatory ethos of PAR, where the legitimacy of knowledge emerges from collective inquiry rather than external prescription (Han & Sun, 2024; Zhong et al., 2024). It also set the stage for a more meaningful engagement with AI tools, as teachers could immediately see their relevance to everyday teaching challenges.

The core of the intervention consisted of hands-on workshops focused on prompt engineering and AI-assisted instructional design. Teachers were introduced to generative AI platforms and guided through practical exercises in constructing prompts to generate lesson plans, coding exercises, and contextualized learning materials. Importantly, these activities were not conducted in isolation; they were embedded within collaborative group work, where teachers shared ideas, experimented with different prompt strategies, and provided feedback to one another. This collaborative dimension played a significant role in reducing initial anxiety toward AI technologies, which several participants had previously perceived as complex or inaccessible. As noted by one teacher (D.P.), “At first I thought AI was too advanced for us, but when we tried it together, it became something we could explore step by step.”

This process of collective experimentation and mutual support is central to what has been described as human-centered learning ecosystems, where technology functions as an enabler of social interaction rather than a replacement for it (Dalvi-Esfahani et al., 2023; Khulsum et al., 2025; Kittipanya-ngam et al., 2025). In this study, AI did not operate as an autonomous instructional agent, but as a catalyst for dialogue, creativity, and reflection among teachers. The act of crafting prompts, interpreting AI-generated outputs, and refining them based on pedagogical considerations required teachers to engage in higher-order thinking, bridging technical understanding with instructional intent. Over time, this iterative engagement contributed to a gradual shift in how teachers perceived both technology and their own roles within the learning process.

The reflective component of the PAR cycles further deepened this transformation. After each phase of implementation, teachers participated in guided reflection sessions, where they discussed their experiences, challenges, and insights. These sessions revealed a growing awareness of the pedagogical possibilities of AI, as well as a more critical stance toward its limitations. For instance, one participant (L.W.) observed, “AI can give us ideas quickly, but we still need to adjust them so they fit our students.” This statement illustrates an emerging understanding that effective use of AI requires not only technical skill but also contextual judgment. Such reflections resonate with the notion of transformative learning, where individuals revise their assumptions and develop new frames of reference through critical reflection (Daly et al., 2025; Köster et al., 2025).

Evidence of this transformation was also visible in classroom practices. During the action phase, teachers began to implement AI-generated materials in their lessons,

particularly in coding-related topics. Observations indicated increased student engagement, as lessons became more interactive and relevant to local contexts. Teachers reported that AI helped them generate examples and exercises that were previously difficult to design due to time constraints or limited resources. At the same time, they became more attentive to aligning these materials with students' needs and learning levels. This dual process of adoption and adaptation reflects a deeper internalization of technopedagogical principles, moving beyond surface-level use toward more intentional and reflective practice.

Another notable aspect of the intervention was the gradual emergence of teacher agency. As teachers gained confidence in using AI tools, they began to take initiative in exploring new applications and sharing their experiences with peers. This shift was particularly evident in the later stages of the PAR cycles, where participants started to propose their own ideas for integrating AI into different subjects and learning scenarios. One teacher (A.N.) described this change as "moving from following instructions to creating our own way of teaching with AI." Such developments suggest that the intervention not only enhanced technical competence but also fostered a sense of professional empowerment, which is essential for sustainable innovation in education (Si Mohammed et al., 2024; Tay et al., 2021; Tekic & Tekic, 2024).

Importantly, the service-learning dimension of the intervention ensured that these transformations were grounded in real-world relevance. Teachers were encouraged to design materials that addressed local contexts, such as incorporating everyday phenomena from their communities into coding exercises. This emphasis on contextualization reinforced the idea that technology should serve as a bridge between abstract knowledge and lived experience, rather than an external imposition. It also contributed to a more meaningful engagement with AI, as teachers could see its direct impact on student learning.

Enhancement of Generative AI Literacy and Prompt Engineering Skills

The intervention produced a marked enhancement in teachers' literacy regarding generative artificial intelligence (AI), particularly in their ability to construct and refine prompts as a core operational skill. This development was not merely incremental but reflected a substantive shift in how teachers engaged with digital tools as cognitive partners in instructional design. Quantitative findings from the pre- and post-assessment indicate a significant increase in overall competence, with N-gain scores falling within the moderate to high improvement range across key indicators, including conceptual understanding of generative AI, prompt formulation, and application in lesson development. Items that initially revealed near-zero familiarity, such as structuring iterative prompts, specifying constraints, or contextualizing AI outputs, showed the highest gains, suggesting that the intervention effectively addressed foundational gaps.

These quantitative improvements are further substantiated by qualitative evidence gathered through interviews, observations, and document analysis. At the beginning of the study, most participants associated AI with passive consumption of information, often equating it with search engines or automated text generators. As one teacher (R.S.) explained,

"I thought AI just gives answers, like searching on the internet, but I did not know we could guide it." This perception gradually evolved as teachers engaged in structured prompt engineering activities. By the later stages of the intervention, participants demonstrated an emerging awareness of AI as a responsive system that requires precise and purposeful input. Another participant (D.P.) reflected, "Now I understand that the result depends on how we ask. If the prompt is clear, the output becomes more useful for teaching." Such reflections indicate a transition from passive interaction to intentional communication with AI systems.

This transformation can be understood through the lens of AI literacy, which has recently been conceptualized as a critical competency for educators in the digital age. AI literacy extends beyond technical familiarity to include the ability to critically interpret, evaluate, and co-create with AI systems (Bhimani et al., 2022; Molleví Bortoló et al., 2023). Within this framework, prompt engineering emerges as a central skill, functioning as the interface through which human intent is translated into machine-generated output. In the context of this study, teachers' growing proficiency in prompt construction reflects their increasing capacity to engage with AI not as a black box, but as a tool that can be shaped and directed according to pedagogical goals.

The process through which this competence developed was deeply embedded in the hands-on and iterative nature of the intervention. Teachers were not only introduced to basic prompt structures but were also encouraged to experiment with variations, test outputs, and refine their inputs based on the results obtained. This trial-and-error process was supported by collaborative discussions, where participants shared strategies and reflected on what constituted an effective prompt. Over time, several patterns of improvement became evident. Teachers began to incorporate more specific instructions, such as defining learning objectives, specifying student levels, and embedding contextual elements relevant to their local environment. They also developed an awareness of the need to critically evaluate AI-generated content, recognizing that outputs often required adaptation to align with curricular standards and student needs.

Document analysis of the instructional materials produced during the intervention provides further evidence of this progression. Early outputs generated by teachers tended to be generic, lacking contextual relevance and pedagogical depth. However, as their prompt engineering skills improved, the materials became more structured, context-sensitive, and aligned with learning outcomes. For example, in developing coding exercises, teachers initially generated abstract problems that were disconnected from students' experiences. In later iterations, these tasks were recontextualized using local scenarios, such as everyday activities in coastal communities, making them more relatable and engaging. This shift illustrates how improved prompt design enabled teachers to harness AI for creating meaningful and situated learning experiences.

Development of Contextualized Digital Teaching Materials: From Abstraction to Local Relevance

One of the most tangible outcomes of the intervention was the development of contextualized digital teaching materials produced by the participating teachers, reflecting a clear progression from abstract, generic outputs toward locally grounded and pedagogically meaningful resources. These materials, which included lesson plans (RPP), student worksheets (LKS), and modular teaching units, were not only products of technical engagement with generative AI but also embodiments of a deeper pedagogical shift. Rather than relying on pre-existing or standardized content, teachers began to design learning resources that resonated with the lived experiences of their students, particularly within the socio-cultural context of rural communities in Maluku Tengah. This transition illustrates how generative AI, when mediated through reflective and participatory processes, can support the localization of knowledge rather than its homogenization.

At the early stage of the intervention, document analysis revealed that AI-generated materials tended to be decontextualized and often mirrored global or urban-centric examples. For instance, initial coding exercises produced by teachers frequently referenced scenarios such as urban transportation systems or generic technological environments that were unfamiliar to students. As one participant (M.L.) noted during reflection, “The examples looked good, but they did not feel close to our students’ daily life.” This recognition marked a critical turning point in how teachers approached the use of AI. Through iterative cycles of prompt refinement and collaborative discussion, they began to intentionally embed local elements into their instructional designs, such as coastal livelihoods, traditional markets, and community practices. These contextual adaptations were not incidental but emerged as deliberate pedagogical choices, informed by teachers’ intimate knowledge of their students’ environments.

The evolution of these materials demonstrates an increasing alignment between technological affordances and pedagogical intent. Teachers learned to use prompt engineering not only to generate content efficiently but also to guide AI outputs toward specific cultural and contextual dimensions. For example, in designing coding tasks, teachers began to incorporate locally relevant narratives, such as simulating fish trading activities or modeling simple algorithms based on daily routines in the community. One teacher (A.N.) explained, “When I changed the prompt to include local situations, the results became more meaningful and easier for students to understand.” This shift highlights the role of prompt design as a bridge between abstract computational concepts and concrete learning experiences, enabling students to engage with content in ways that are both cognitively and culturally accessible.

From a theoretical perspective, this process can be understood through the lens of context-aware AI in education, which emphasizes the importance of aligning technological systems with the cultural, social, and environmental contexts in which learning occurs (Isnandar et al., 2023; Silalahi, 2025). In this study, AI was not treated as a neutral or universal

tool but as a flexible resource that could be shaped to reflect local realities. This approach challenges the assumption that digital innovation necessarily leads to standardization, instead demonstrating that, when used critically, AI can support the diversification of pedagogical practices. The teachers' ability to contextualize AI-generated content also reflects a deeper level of technopedagogical integration, where decisions about technology use are guided by an understanding of learners' needs and backgrounds.

Observational data further indicate that the use of contextualized materials had a noticeable impact on classroom dynamics. Lessons that incorporated locally relevant examples were associated with higher levels of student engagement, as students were more able to relate abstract concepts to familiar situations. Teachers reported that students participated more actively in discussions and demonstrated greater confidence in completing tasks. One participant (S.R.) observed, "When the examples are about their own environment, students become more interested and ask more questions." While the primary focus of this study was on teacher competence, these observations suggest that the benefits of contextualized AI-supported materials extend to student learning experiences, reinforcing the value of culturally responsive pedagogy.

The development of these materials also reflects the iterative and reflective nature of the PAR methodology. Teachers did not arrive at contextualized designs immediately; rather, they engaged in cycles of experimentation, feedback, and revision. During reflection sessions, participants shared their materials, discussed challenges, and collectively identified strategies for improvement. This collaborative process allowed teachers to learn not only from their own experiences but also from those of their peers, creating a shared repertoire of practices for contextualizing AI outputs. Over time, this led to a more sophisticated understanding of how to balance efficiency with relevance, leveraging AI's generative capacity while maintaining pedagogical integrity.

The shift toward contextualization also contributed to a redefinition of teachers' roles in the design of learning materials. Instead of acting as consumers of ready-made content, teachers positioned themselves as designers who actively shape the learning experience. This change was evident in how they approached lesson planning, with increased attention to aligning objectives, activities, and assessments within a coherent and context-sensitive framework. The integration of AI into this process did not diminish their agency; rather, it expanded their capacity to explore multiple design possibilities and to refine them based on contextual considerations.

The findings also highlight certain challenges associated with contextualizing AI-generated materials. Teachers noted that achieving culturally relevant outputs required multiple iterations of prompts and careful evaluation of results. In some cases, AI systems produced content that was either too generic or misaligned with local realities, requiring further adaptation. However, these challenges were generally perceived as part of the learning process rather than as barriers. As one teacher (D.P.) remarked, "It takes time to get the right result, but once we understand how to guide the AI, it becomes easier." This

perspective underscores the importance of sustained practice and support in developing effective AI-mediated design skills.

Reconstructing Teacher Identity: From Technology Users to Co-Creators of Learning

A central transformation observed throughout the intervention was the gradual reconstruction of teacher identity, moving from a predominantly passive role as technology users toward a more active position as co-creators of learning. This shift did not occur abruptly; rather, it unfolded through iterative cycles of engagement, reflection, and collaborative practice embedded within the Participatory Action Research (PAR) design. Initially, most teachers positioned themselves as recipients of externally provided tools and instructions, often expressing uncertainty about their capacity to meaningfully integrate digital technologies into their teaching. Technology, including generative AI, was perceived as something to be "used" rather than something to be shaped. As one participant (R.S.) explained in the early phase, "We usually just follow what is given. Technology is already made, and we just try to apply it." This orientation reflects a limited sense of professional agency, where teachers' roles are confined to implementation rather than innovation.

As the intervention progressed, however, a notable shift began to emerge in how teachers perceived their relationship with technology and with their own pedagogical practice. Through hands-on engagement with generative AI tools, particularly in the context of prompt engineering and instructional design, teachers were gradually exposed to the idea that digital technologies are not fixed entities but flexible systems that can be directed, adapted, and co-constructed. This realization was reinforced through collaborative activities, where participants worked together to design, test, and refine AI-supported learning materials. In these spaces, teachers were not merely executing predefined tasks; they were making decisions, experimenting with alternatives, and reflecting on the outcomes of their choices. Such experiences played a crucial role in expanding their sense of ownership over the learning process.

This evolving sense of ownership is closely related to the concept of professional agency, which refers to the capacity of teachers to act purposefully and constructively to direct their professional growth and influence their work environment (Hafiar et al., 2025; Tian & Zhang, 2023). In the context of digital transformation, agency becomes particularly significant, as teachers are required to navigate rapidly changing technological landscapes while maintaining pedagogical coherence. The findings of this study suggest that agency is not simply an individual trait but is developed through supportive environments that encourage participation, experimentation, and reflection. The PAR framework provided such an environment by positioning teachers as co-researchers who actively contributed to the design and evaluation of the intervention.

Evidence of this agency development is visible in both discourse and practice. During reflection sessions, teachers began to articulate their ideas more confidently, proposing alternative ways of using AI in their classrooms and critically evaluating the outputs generated by the technology. One participant (A.N.) noted, "Before, I waited for instructions, but now I

try to create my own approach with AI, depending on what my students need." This statement captures a subtle yet significant shift from compliance to initiative, indicating that teachers were beginning to see themselves as capable of shaping their instructional strategies rather than merely following prescribed models. Similarly, another teacher (D.P.) reflected, "AI is not replacing us. It is helping us think differently about how we teach." Such perspectives illustrate a redefinition of the teacher's role in relation to technology, where AI is understood as a collaborative partner rather than a dominant force.

Classroom observations further support this transformation. Teachers who initially relied on static materials and teacher-centered approaches began to implement more dynamic and interactive lessons, integrating AI-generated content that they had personally designed and adapted. Importantly, these changes were not limited to the use of new tools but extended to broader pedagogical orientations. Teachers demonstrated greater willingness to experiment, to adjust their plans based on student responses, and to incorporate feedback into subsequent lessons. This adaptability reflects a more agentic stance, where teachers actively respond to the complexities of their teaching context rather than adhering rigidly to predetermined structures.

The co-creative dimension of this transformation is particularly noteworthy. Through their engagement with generative AI, teachers were not only designing materials but also engaging in a dialogic process with the technology itself. Prompt engineering, in this sense, became a form of interaction where teachers articulated their pedagogical intentions and negotiated the outputs produced by the AI. This process required them to think critically about the alignment between content, context, and learning objectives, reinforcing their role as designers of learning experiences. Over time, teachers began to see AI as an extension of their creative capacity, enabling them to explore new possibilities while retaining control over the final outcomes.

At the same time, the collaborative nature of the intervention contributed to a collective dimension of agency. Teachers did not operate in isolation; they learned from one another, shared challenges, and co-developed strategies for integrating AI into their practice. This collective engagement fostered a sense of professional community, where innovation was not an individual endeavor but a shared process. As one participant (S.R.) observed, "We are learning together, not competing. When someone finds a better way, we all try it." Such dynamics are essential for sustaining change, as they create a supportive environment in which teachers feel empowered to take risks and to continuously refine their practice.

It is also important to acknowledge that this reconstruction of teacher identity was not without tension. Some participants initially expressed concerns about their ability to keep up with technological developments or about the reliability of AI-generated content. However, these concerns were gradually mitigated through practice and reflection, as teachers developed greater confidence in their ability to critically engage with technology. Rather than eliminating uncertainty, the intervention helped teachers to navigate it more effectively, viewing challenges as opportunities for learning rather than as barriers.

The Emergence of the AI-Supported Technopedagogical Reconstruction Model

The culmination of the iterative processes undertaken in this study is reflected in the emergence of an integrative conceptual framework referred to as the AI-Supported Technopedagogical Reconstruction Model. This model did not arise as a predefined structure imposed at the outset of the research; rather, it evolved organically through the cyclical dynamics of Participatory Action Research (PAR), grounded in empirical findings and continuously refined through collaborative reflection with participants. At its core, the model represents a synthesis of four interrelated domains, generative artificial intelligence (AI), the Technological Pedagogical Content Knowledge (TPACK) framework, service-learning, and PAR, each contributing distinct yet complementary dimensions to the reconstruction of teacher competence in a rural educational context.

The integration of generative AI within this model functions as both a catalyst and a mediating tool. Unlike traditional digital tools that primarily support content delivery, generative AI introduces a dynamic layer of interaction, enabling teachers to co-create instructional materials, simulate problem-solving scenarios, and explore alternative pedagogical designs. However, the effectiveness of this integration is contingent upon teachers' ability to align AI outputs with pedagogical intentions, a process that requires more than technical proficiency. It demands an understanding of how technology intersects with content and pedagogy, which is precisely where the TPACK framework becomes essential. Within the model, TPACK operates as the conceptual backbone, guiding teachers in making informed decisions about when, why, and how to use AI in ways that enhance learning rather than distract from it (Madureira et al., 2023; Yunita et al., 2024).

What distinguishes this model from conventional applications of TPACK is the way in which generative AI reshapes the relationships among its components. Rather than treating technology as an external layer to be integrated into existing pedagogical practices, AI becomes embedded within the very process of knowledge construction. Teachers engage with AI not only to access information but to generate, adapt, and contextualize content in real time. This interaction transforms the static representation of TPACK into a more fluid and iterative process, where knowledge domains are continuously negotiated and reconfigured. As one participant (A.N.) reflected, "Using AI makes me think about my subject, my teaching method, and the technology all at once. They are no longer separate." This observation illustrates how the model fosters a more holistic form of technopedagogical reasoning.

The service-learning component adds a critical contextual and ethical dimension to the model. By grounding learning activities in real-world community contexts, service-learning ensures that the use of AI is not detached from the social realities of students and teachers. In this study, teachers were encouraged to design instructional materials that reflected local practices, challenges, and cultural narratives, thereby bridging the gap between global technological innovations and local educational needs. This alignment reinforces the principle that meaningful learning occurs when knowledge is situated within authentic contexts (Perdana et al., 2025; Shaari et al., 2024). Within the model, service-

learning acts as a contextual anchor, ensuring that technopedagogical reconstruction is not merely a technical exercise but a socially responsive process.

The role of PAR in this framework is equally foundational, as it provides the methodological structure through which the other components are operationalized. PAR introduces a cyclical process of diagnosing, planning, acting, observing, and reflecting, enabling continuous adaptation and refinement of both practice and understanding (Fosso Wamba et al., 2021; Shahzad et al., 2023). More importantly, it redefines the position of teachers from passive recipients of training to active co-researchers who contribute to the generation of knowledge. This participatory orientation is crucial for fostering professional agency and ensuring that the model remains responsive to the evolving needs of its users. As one teacher (S.R.) noted during the reflection phase, “We are not just learning a method; we are building it together based on our experience.” This statement captures the essence of PAR as a process of collective knowledge construction.

The interaction among these four components can be understood as a dynamic system rather than a linear sequence. Generative AI provides the technological affordances that enable new forms of content creation and pedagogical experimentation. TPACK offers the conceptual lens through which these affordances are interpreted and applied. Service-learning situates these practices within meaningful social contexts, while PAR ensures that the entire process remains iterative, reflective, and participatory. Together, these elements create a feedback loop in which each component reinforces and reshapes the others, leading to a continuous reconstruction of teacher competence.

From a theoretical perspective, the emergence of this model aligns with recent calls for more integrative frameworks in AI-enhanced education, which emphasize the need to move beyond isolated technological interventions toward multidimensional approaches that account for pedagogical, social, and contextual factors (Garcia-del-Real & Alcaráz, 2024). Existing models often treat these dimensions separately, resulting in fragmented understandings of how AI can be effectively integrated into educational practice. In contrast, the AI-Supported Technopedagogical Reconstruction Model offers a more holistic perspective, demonstrating how these elements can be woven together into a coherent and adaptable framework.

Empirically, the model is grounded in the observed transformations among participating teachers, including improvements in AI literacy, the development of contextualized teaching materials, and the emergence of professional agency. These outcomes are not treated as isolated indicators but as interconnected manifestations of a broader process of reconstruction. The model thus serves not only as a descriptive representation of what occurred in this study but also as a conceptual tool for understanding how similar transformations might be facilitated in other contexts, particularly in underserved or resource-constrained environments.

At the same time, it is important to recognize that the model remains context-sensitive and should not be interpreted as a universal solution. Its effectiveness is closely tied

to the specific conditions under which it was developed, including the participatory nature of the research process and the emphasis on local relevance. Nevertheless, its underlying principles, integration, participation, contextualization, and reflection, offer valuable insights for the design of future teacher development programs in the era of AI.

CONCLUSION

This study demonstrates that the reconstruction of teachers' technopedagogical competence in rural educational contexts can be meaningfully achieved through the integration of generative artificial intelligence within a participatory and context-sensitive service-learning framework. By situating teachers as active co-participants in a cyclical process of reflection, design, and implementation, the research shows that competence development is not merely a matter of acquiring technical skills, but involves a deeper transformation in how teachers conceptualize and enact their pedagogical roles. The findings indicate that when generative AI is embedded within collaborative and locally grounded practices, it can support teachers in bridging the gap between technological innovation and classroom realities, enabling them to design learning experiences that are both contextually relevant and pedagogically intentional. In this process, teachers move beyond the functional use of technology toward a more agentic and creative engagement, where they are able to critically shape and adapt AI-generated outputs in alignment with their instructional goals and students' needs. The study thus affirms that participatory approaches, particularly those grounded in Participatory Action Research, are effective in fostering sustainable professional growth by aligning technological integration with teachers' lived experiences. At a conceptual level, the emergence of the AI-Supported Technopedagogical Reconstruction Model offers a nuanced contribution by illustrating how generative artificial intelligence, the Technological Pedagogical Content Knowledge framework, service-learning, and participatory methodologies can be interwoven into a coherent framework for teacher development. This integrative perspective not only addresses the limitations of fragmented training models but also provides a contextually adaptable pathway for enhancing teacher competence in developing regions. While the findings are rooted in a specific rural setting, they suggest broader implications for the design of inclusive and scalable professional development initiatives that respond to the evolving demands of digital education without detaching from local realities.

ETHICAL STATEMENT AND DISCLOSURE

This study was conducted in accordance with established ethical principles, including informed consent, protection of informants' confidentiality, and respect for local cultural values. Special consideration was given to participants from vulnerable groups to ensure their safety, comfort, and equal rights to participate. No external funding was received, and the authors declare no conflict of interest. All data and information presented were collected through valid research methods and have been verified to ensure their accuracy and

reliability. The use of artificial intelligence (AI) was limited to technical assistance for writing and language editing, without influencing the scientific substance of the work. The authors express their gratitude to the informants for their valuable insights, and to the anonymous reviewers for their constructive feedback on an earlier version of this manuscript. The authors take full responsibility for the content and conclusions of this article.

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