

International Journal of Learning, Teaching and Educational Research
 Vol. 25, No. 4, pp. 722-744, April 2026
<https://doi.org/10.26803/ijlter.25.4.33>
 Received Feb 14, 2026; Revised Apr 7, 2026; Accepted Apr 8, 2026

From Activation to Transformation: A Multi-Site Case Study of Digital Competence Development in Indonesian Non-Formal Teacher Professional Learning Communities

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Abstract. This study investigates how non-formal Teacher Professional Learning Communities (PLCs) sustain digital competence development across urban-industrial, semi-rural, and suburban contexts in Indonesia, addressing the limited process-explicit understanding of how voluntary PLCs generate sustained digital competence beyond episodic training models. Using an interpretive multi-site case study design, data were collected from 18 participants across three PLCs through semi-structured interviews, non-participant observations, and analysis of 47 artefacts, and analyzed using iterative coding and cross-case comparison to identify recurring mechanisms underpinning community-based digital upskilling. Findings demonstrate that PLC sustainability is not determined by structural arrangements alone, but by a recurring sequence of activation, artefact-mediated co-design, iterative reflection, role transformation, and diffusion. Across sites, digital upskilling was catalyzed by leadership-framed initiation, intensified through AI-supported workshops and collaborative artefact production, and stabilized through structured reflection routines that redistributed leadership roles over time. Participation trajectories shifted from peripheral observation to distributed facilitation, indicating professional identity consolidation and increased collective agency. The study proposes the Community-Based Digital Upskilling Cycle (CBDUC) as a process-explicit model that extends existing PLC frameworks by explicating mechanism-level processes through which collaborative participation becomes sustained professional practice in non-formal contexts. Theoretically, the study reframes PLCs as recurring mechanism systems rather than static organizational structures. Practically, it

Citation:
 Musa, S., & Nurhayati, S. (2026). From Activation to Transformation: A Multi-Site Case Study of Digital Competence Development in Indonesian Non-Formal Teacher Professional Learning Communities. *International Journal of Learning, Teaching and Educational Research*, 25(4), 722-744. <https://doi.org/10.26803/ijlter.25.4.33>

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highlights the importance of protected collaboration time, artefact diffusion infrastructures, and supported coordinative roles in sustaining digital transformation within non-formal teacher networks, while offering implications for policy and design of scalable teacher professional learning systems in resource-variable settings.

Keywords: community-based digital upskilling; digital competence development; distributed leadership; non-formal teacher networks; professional learning communities

1. Introduction

The intensification of digital transformation across educational systems has redefined the epistemic and practical foundations of teachers' professional competence. Digital competence is no longer understood as an auxiliary skill but as a core dimension of pedagogical expertise, encompassing the design of technology-enhanced learning environments, the orchestration of digitally mediated interaction, and the integration of digital tools within disciplinary practice. In Indonesia, national policies promoting digitalization in education and teacher professional development have accelerated the integration of digital tools in classrooms; however, disparities in infrastructure, access, and teacher preparedness continue to challenge equitable implementation across regions.

Despite sustained policy prioritization and significant investment in professional development infrastructures, the long-term consolidation of teachers' digital competence remains uneven. Empirical scholarship published between 2020 and 2025 demonstrates that sustainable digital competence development cannot be reduced to isolated training events; rather, it requires systemic coherence across structural, institutional, psychological, and contextual domains (El-Hamamsy et al., 2024; Jiménez-Hidalgo et al., 2025). Sustainability is thus conceptualized as an ongoing process embedded within professional learning ecosystems rather than a discrete outcome.

Emerging models emphasize that durability depends on perceived pedagogical usefulness, implementation feasibility, distributed leadership, and continuous institutional support. The Sustainable Adoption of Digital Education (SADE) model positions perceived usefulness and systemic scaffolding as interdependent determinants of sustained engagement (El-Hamamsy et al., 2024). Letnes (2025) highlights the mediating role of ICT coordinators and distributed leadership structures in embedding digital practices within school routines, while Jiménez-Hidalgo et al. (2025) underscore the need for strategic alignment between professional development initiatives and governance frameworks.

However, persistent structural constraints complicate these trajectories. Infrastructural limitations—including unreliable connectivity, limited device access, and insufficient software ecosystems—continue to restrict meaningful digital integration (Iqbal et al., 2025). These constraints intersect with affective pressures, as teachers report stress and cognitive overload during accelerated digital transitions (Borzenko et al., 2025). In Indonesian contexts, these challenges

are further compounded by regional disparities between urban and rural areas, uneven institutional support, and variability in teacher access to continuous professional learning opportunities. Funding inequities and context-insensitive professional development designs further attenuate reform efforts (Díaz-Suárez et al., 2025; Kyriakou et al., 2026). Together, these findings reveal a structural paradox: digital competence is positioned as indispensable, yet its sustainable realization remains fragile and context dependent.

A central explanation for this fragility lies in the dominance of episodic, workshop-based professional development paradigms. Research consistently shows that short-duration, decontextualized workshops exert limited influence on durable instructional transformation (Hutchison & Woodward, 2018). Longitudinal studies indicate that instructional gains frequently diminish once formal programs conclude (Sandholtz et al., 2019). Transmissive formats also restrict opportunities for iterative experimentation and reflective inquiry, processes essential for sustained pedagogical change (Vasconcelos & Rocha, 2024). In practice, many teachers report difficulty translating workshop-based learning into classroom implementation due to lack of follow-up support and collaborative structures. While such initiatives may facilitate initial exposure to digital tools, they rarely institutionalize collaborative routines capable of stabilizing practice.

In contrast, sustained and collaborative professional learning architectures demonstrate stronger potential for enduring digital transformation. Extended development trajectories incorporating mentoring, collective inquiry, and structured reflection are associated with more durable instructional integration (Amemasor et al., 2025). Within this landscape, Professional Learning Communities (PLCs) have gained prominence as mediating infrastructures of professional growth. PLCs are characterized by shared vision, collaborative inquiry, reflective dialogue, and distributed leadership.

Empirical evidence links PLC participation with enhanced digital instructional integration and innovation capacity (Rasdiana et al., 2025). Structural equation modeling further demonstrates that PLC engagement mediates the relationship between digital professional development and classroom enactment, amplifying the effects of leadership and institutional preparedness (Amemasor et al., 2025). Through sustained interaction and co-design, PLCs cultivate deeper pedagogical reasoning and confidence in technology integration (Ngao & Sang, 2024).

Nevertheless, an analytical gap persists. Much of the PLC literature privileges structural descriptors and outcome indicators, while comparatively underdeveloping process-explicit explanations of how recurrent collaborative participation generates sustained digital competence over time. Where mechanisms are discussed, they are typically situated within institutionally mandated, school-embedded PLCs operating in relatively stable infrastructures. Voluntary and non-formal educator communities, particularly those navigating resource variability, remain insufficiently theorized in relation to longitudinal digital upskilling. Specifically, limited research explains how iterative

participation processes, artefact production, and collaborative routines interact over time to stabilize digital competence in non-formal settings.

Research on non-formal PLCs highlights adaptive, self-directed modalities of professional learning beyond formal mandates (Siebold et al., 2025). Digital platforms facilitate cross-boundary collaboration and distributed knowledge exchange (Pasquini & Eaton, 2021), yet such communities frequently operate within contexts marked by infrastructural fragility and uneven policy support (Wu & Liu, 2024). Studies in Global South settings illustrate both the transformative promise of PLCs and the decisive influence of contextual variables, including leadership capacity, material resources, and socio-economic disparities (Nguyen et al., 2024; Tegegne et al., 2025). Although PLC engagement is associated with enhanced collaboration and instructional refinement, sustainability remains highly context dependent.

Synthesizing this literature reveals three key gaps. First, existing studies emphasize outcomes rather than the mechanisms of sustained digital competence development (Amemasor et al., 2025). Second, most research focuses on formal, school-embedded PLCs, with limited attention to voluntary or non-formal communities (Sandholtz et al., 2019). Third, there is insufficient explanation of how collaborative processes evolve over time under resource variability (Borzenko et al., 2025). This study addresses this gap through a multi-site case analysis of three educator communities in West Java, Indonesia, operating as non-formal Professional Learning Communities across urban-industrial, semi-rural, and suburban contexts. Employing a process-oriented analytic lens, the study examines how collaborative participation, artefact production, reflective dialogue, and contextual adaptation interact to stabilize and reproduce digital upskilling practices under infrastructural variability.

The novelty of this research lies in its reconceptualization of PLC-driven digital competence development as a dynamic, iterative process rather than merely a structural correlate of positive outcomes. Unlike existing PLC frameworks that emphasize structural characteristics or outcome relationships, this study explicates mechanism-level processes linking participation, artefact mediation, and role transformation over time. It advances PLC scholarship by articulating mechanism-level explanations of how recurrent participation becomes embedded in professional practice over time. Extending PLC theory beyond institutionally embedded settings, it theorizes voluntary, cross-boundary educator communities as adaptive professional learning infrastructures and introduces the Community-Based Digital Upskilling Cycle (CBDUC) as an analytic model capturing cyclical, artefact-mediated processes of competence consolidation and professional role reconfiguration.

The study is guided by the following research questions:

- (1) How do non-formal educator communities operationalize PLC principles to sustain digital upskilling over time?
- (2) Through what recurring mechanisms does collaborative participation translate into durable digital competence development?

- (3) How do contextual and infrastructural conditions shape the stability and adaptability of community-based PLC processes?
- (4) How does sustained participation in non-formal PLC structures reconfigure educators' professional roles in digital practice?

By foregrounding processual mechanisms within non-formal PLC contexts, this study contributes a theoretically refined and context-sensitive account of sustained digital competence development, providing empirical and theoretical insights relevant to policy, practice, and future research on digital professional learning in resource-variable educational systems, advancing scholarly debates in PLC research and digital professional learning.

2. Literature Review

Professional Learning Communities (PLCs) are conceptualized as professional ecosystems that institutionalize collaboration as a mechanism for instructional improvement and professional capital development. Rather than informal collegial gatherings, PLCs are structured through interdependent dimensions – shared vision, collective inquiry, reflective dialogue, and enabling leadership – that shape how teachers generate and refine professional knowledge (Tinoca et al., 2025). From a theoretical perspective, PLCs are also understood as socially situated learning environments in which professional knowledge is co-constructed through interaction and shared practice. Contemporary scholarship cautions that when these dimensions are reduced to managerial compliance, PLCs risk becoming procedural rather than transformative.

Shared vision aligns educators around common instructional purposes, yet its impact depends on authentic internalization rather than symbolic consensus (Tinoca et al., 2025). Collective inquiry forms the epistemic core of PLCs, requiring systematic engagement with evidence and iterative refinement of practice (Siebold et al., 2025). Reflective dialogue operationalizes inquiry by surfacing assumptions and enabling critique, though its effectiveness depends on relational trust. Leadership mediates these processes by safeguarding collaborative time and legitimizing teacher agency; excessive formalization, however, can undermine ownership (Tinoca et al., 2025). PLC effectiveness therefore hinges on enacted coherence among these dimensions rather than their nominal presence.

In digital reform contexts, PLCs are increasingly framed as infrastructures for developing teachers' digital instructional competence. Empirical studies report consistent associations between PLC participation and stronger technology integration practices (Trevisan et al., 2024). Within PLCs, digital competence is socially mediated: teachers collaboratively experiment with tools, adapt technologies to disciplinary needs, and refine instructional strategies through peer interaction. This perspective aligns with socio-constructivist views of digital competence as a practice-based capability developed through participation, rather than as an individual technical skill.

However, the literature remains largely outcome oriented. Digital competence is commonly measured through integration indices or self-reported indicators (Bergkvist et al., 2023). Although mediation analyses suggest that PLCs translate professional development into classroom enactment (Amemasor et al., 2025), they rarely unpack the interactional and organizational processes through which repeated collaboration stabilizes competence over time. In particular, limited attention has been given to how artefacts – such as lesson plans, digital materials, and AI-generated resources – mediate collaborative learning and support cumulative knowledge building. As a result, an explanatory gap persists between correlation and mechanism.

PLC research has predominantly examined school-embedded communities supported by formal leadership and scheduled collaboration time. In contrast, voluntary or non-formal PLCs emerge through self-directed participation and cross-boundary networking (Brynildsen et al., 2022). These communities may foster innovation and contextual responsiveness, particularly under resource variability (Rasdiana et al., 2025). Yet voluntary PLCs operate under structural precarity. Participation depends on teacher motivation and available time, while limited infrastructural and institutional support can disrupt continuity (Brynildsen et al., 2022). This is particularly evident in Global South contexts, including Indonesia, where disparities in infrastructure and institutional support shape participation dynamics. Although the literature acknowledges their adaptive potential, it remains analytically thin regarding how recurring participation generates sustained professional learning, especially in relation to digital competence consolidation.

Across strands, PLCs are consistently associated with collaboration, instructional improvement, and digital integration (Siebold et al., 2025). However, two limitations remain salient: PLC dimensions are often treated as static attributes, and digital-PLC research privileges measurable outcomes over longitudinal process analysis. These limitations are intensified in non-formal and resource-variable contexts where sustainability depends on endogenous participation dynamics. Advanced PLC scholarship therefore requires a process-explicit orientation that foregrounds recurrence, participation trajectories, artefact mediation, and contextual adaptation as explanatory mechanisms.

Such a shift moves analysis from whether PLCs are effective to how collaborative routines become stabilized and reproduced over time. Unlike existing frameworks that emphasize structural dimensions or outcome relationships, the present study responds by introducing the Community-Based Digital Upskilling Cycle (CBDUC) as a mechanism-oriented framework for explicating how non-formal PLC participation consolidates digital competence longitudinally under conditions of resource variability.

3. Methodology

3.1 Research Design

This study used an interpretive multi-site qualitative case study design to understand how non-formal Professional Learning Communities (PLCs) help teachers develop and sustain digital competence. A qualitative case study was chosen because the research focuses on answering “how” and “why” questions in real-life contexts. Case study research is appropriate when a phenomenon cannot be separated from its setting and when the goal is to understand processes in depth rather than to test variables statistically (Yin, 2018). This design is particularly suitable for examining process-based mechanisms and contextual variation across multiple sites.

The study involved three different sites in order to compare patterns across contexts. Using multiple sites helps strengthen the findings because it allows the researcher to see whether similar processes occur in different environments. This follows the idea of replication logic, where each case is treated as a separate but comparable unit of analysis (Yin, 2018). By comparing cases, the study aims to develop broader theoretical insights rather than make statistical generalizations (Johnson et al., 2020). Data collection and analysis were carried out at the same time. As data collected, early findings were reviewed and used to refine interview questions and observation focus. This iterative and concurrent approach enabled progressive refinement of emerging categories and supported analytic rigor.

3.2 Case Selection Logic

The cases were selected using purposive maximum-variation sampling. This means the sites were chosen intentionally to represent different types of contexts while still meeting the same core criteria (Scantlebury & Adamson, 2024). The three research sites were: Non-Formal Teacher Professional Learning Community of Digital Initiative, Kabupaten Bekasi (urban-industrial context); Non-Formal Teacher Professional Learning Community of Collaborative Learning Community, Kabupaten Tasikmalaya (semi-rural context); Non-Formal Teacher Professional Learning Community of Digital Innovation Network, Kota Bogor (suburban context).

These sites were selected based on the following criteria: (a) participation was voluntary and not only based on formal institutional requirements; (b) the community had been active for at least one academic year; (c) members were involved in digital instructional development; (d) meetings were held regularly (at least once a month); and (e) the community agreed to allow observations and access to documents. Bekasi represents an urban area with relatively stable digital infrastructure. Tasikmalaya represents a semi-rural area with moderate technological limitations. Bogor represents a suburban area with mixed levels of support and resources. This sampling strategy enabled examination of both convergence and contextual variation in PLC processes across differing infrastructural conditions.

3.3 Participants, Instruments, and Data Collection Procedures

Participants were selected purposively to represent different roles within each PLC. To be included, participants had to be actively involved in the community for at least six months and directly engaged in digital teaching initiatives. A total of 18 participants were included (six from each site): three coordinators, six facilitators, and nine active teacher members. Their teaching experience ranged from three to twenty-two years. A summary of participant characteristics is provided to enhance transparency and replicability.

The 18 informants consisted of 10 female and 8 male teachers. In terms of educational background, 14 participants held a bachelor's degree in education, while 4 held a master's degree. Subject areas represented included Mathematics (4), Bahasa Indonesia (3), English (3), Science (4), and Social Studies (4). Most participants (n=12) had more than 10 years of teaching experience, while 6 had between 3–9 years of experience. All coordinators had more than 12 years of teaching experience and had previously participated in district-level professional development programs. Facilitators were typically teachers with demonstrated digital skills who supported peers in lesson design and technology use.

Active members were classroom teachers who regularly participated in PLC meetings and digital experimentation activities. Across the three sites, participants reported engaging in activities such as collaborative lesson planning, digital platform trials (e.g., learning management systems and AI-assisted tools), peer feedback sessions, and workshop facilitation. This diversity in roles, experience levels, and subject backgrounds ensured variation in perspectives while maintaining relevance to the study focus on digital competence development.

The semi-structured interview guide was developed based on the research questions and key PLC concepts such as shared vision, collaborative inquiry, reflective dialogue, leadership, and artefact creation. To ensure content validity, the interview guide was reviewed by two qualitative research experts. A pilot interview with two teachers outside the research sites was conducted to check clarity and relevance. Revisions were made based on their feedback. An observation guide was also developed to focus on interaction patterns, collaboration routines, and digital activities.

Data were collected over six months through four stages: Stage 1: Site entry and preparation (Weeks 1–4). Ethical approval was obtained, informed consent was collected, and rapport was established. Stage 2: Interviews (Weeks 5–10). Eighteen semi-structured interviews lasting 60–90 minutes were conducted. All interviews were audio-recorded and transcribed verbatim. Participants reviewed their transcripts to confirm accuracy. Stage 3: Observations (Weeks 8–18). Twelve non-participant observations (four per site) were conducted. Observations focused on meeting discussions, collaborative planning, decision-making processes, and reflective conversations. Field notes were written within 24 hours. Stage 4: Document collection (Weeks 8–24). A total of 47 artefacts were collected, including lesson plans, digital materials, workshop slides, and communication records.

These documents were organized and analyzed to understand development processes. Throughout the study, the researcher kept analytic memos to record reflections and emerging interpretations. Data collection continued until sufficient depth and redundancy of themes were achieved across data sources, ensuring analytic adequacy rather than simple data saturation.

3.4 Cross-Case Analysis and Reliability Procedures

Data analysis followed three main phases. Phase 1: Within-case analysis. All data were organized using qualitative analysis software (NVivo 14). Open coding was used to identify key actions, routines, and challenges within each site. Axial coding grouped similar codes into broader categories such as collaborative cycles, feedback processes, and leadership roles. Coding followed an iterative process involving constant comparison across data segments. To improve reliability, 20% of the transcripts were coded by a second researcher. Differences were discussed until agreement was reached. Phase 2: Cross-case comparison.

Patterns identified in each case were compared across the three sites. Tables and matrices were created to identify similarities and differences in PLC processes. Phase 3: Mechanism identification. The analysis focused on identifying recurring sequences of activities that linked collaboration to sustained digital practice. A mechanism was accepted only if it appeared in at least two cases and was supported by at least two types of data (e.g., interviews and observations). This multi-source triangulation strengthened the credibility of identified mechanisms. The goal of analysis was to develop theoretical insights that could be applied to similar contexts, rather than to generalize statistically.

3.5 Trustworthiness, Validity, and Reliability

Trustworthiness was ensured using the criteria of credibility, transferability, dependability, and confirmability. Credibility was strengthened through triangulation of interviews, observations, and documents. Different participant roles were included to capture multiple perspectives. Member checking was conducted by sharing summaries with participants for feedback. Prolonged engagement across six months also supported credibility. Dependability was supported by maintaining a detailed audit trail, documenting sampling decisions, coding steps, and analytic changes. Confirmability was enhanced through reflexive journaling and peer discussions to reduce researcher bias. Transferability was supported by providing detailed descriptions of each site's context, structure, and collaboration practices. Ethical procedures included informed consent, anonymization of institutions and participants, secure storage of data, and ongoing ethical reflection. Ethical clearance for the study was obtained from the Universitas Singaperbangsa Karawang review board prior to data collection.

4. Results and Findings

To strengthen analytical depth and explicitly align findings with the research objectives, this section identifies measurable empirical indicators derived from qualitative data across interviews, observations, and documentary sources. Evidence from multiple data sources (interviews, observations, and artefacts) is

presented within each subsection to illustrate how findings are grounded empirically. Rather than presenting narrative description alone, the results are structured around recurring indicators, cross-case frequency patterns, and mechanism strength across sites. Table 1 presents the core data sources, volume of data collected, and the analytical indicators derived from each source.

Table 1: Summary of Original Data Sources, Indicators, and Analytical Contribution

| Data Collection Technique | Volume | Key Analytical Indicators Identified | Cross-Case Strength |
|------------------------------|-----------------|--|------------------------------|
| Semi-structured Interviews | 18 participants | Activation trigger presence; leadership framing frequency; AI workshop reference density; participation shift narratives | High convergence (3/3 sites) |
| Non-participant Observations | 12 sessions | Co-design cycles observed; AI experimentation episodes; reflection loops documented | High convergence (3/3 sites) |
| Documentary Artefacts | 47 documents | AI-generated modules; revised lesson plans; evidence of iterative modification | Moderate-High (2-3 sites) |
| Field Notes & Analytic Memos | 6 months | Infrastructure constraints; time allocation patterns; motivational persistence | Context-dependent variation |

Across data sources, six dominant empirical indicators were identified. These indicators were consistently supported by triangulated evidence across at least two data sources in each case.

1. Activation Framing Indicator - explicit articulation of shared digital urgency in 15 of 18 interviews.
2. Artefact Production Indicator - documented AI-assisted material generation in all three PLCs.
3. Iterative Revision Indicator - observed review-revise-reapply cycles in 9 of 12 observation sessions.
4. Participation Repositioning Indicator - role transition evidence in 11 of 18 interview narratives.
5. Leadership Mediation Indicator - facilitative coordination present in all three sites, though structurally varied.
6. Contextual Stability Indicator - sustainability strengthened where at least two stabilizing conditions co-occurred.

The convergence of these indicators across sites suggests strong pattern replication rather than isolated narrative reporting. For example, AI workshop references appeared in 83% of interviews (15/18 participants), and artefact modification was visible in 34 of 47 collected documents, demonstrating consistent implementation beyond single-session exposure. Interview narratives further indicated that participants perceived these activities as directly influencing their classroom practices. These indicator-based findings provide analytic grounding for the mechanism interpretation presented in Sections 4.1-4.5. The Results section therefore moves beyond descriptive narration by identifying cross-case replication patterns, relative strength of empirical signals, and alignment with the study's research objective: to explain how non-formal

PLCs sustain digital competence development through recurring process mechanisms.

4.1 Activation Pathways of Non-Formal PLCs (RQ1)

This subsection directly addresses Research Question 1, which examines how non-formal PLCs are initiated and stabilized. The objective was to identify activation mechanisms that explain sustained participation in digital upskilling. Analysis across the three Teacher Professional Learning Communities indicates that PLC activation followed patterned yet context-sensitive mechanisms rather than spontaneous collegial gathering. Activation required a triggering condition combined with the framing of digital upskilling as shared professional work. Interview data revealed that participants frequently described initial engagement as “motivated by shared challenges” and “guided by coordinators who framed digital skills as essential.”

Analysis across the three Nonformal Teacher Professional Learning Communities indicates that PLC activation followed patterned yet context-sensitive mechanisms rather than spontaneous collegial gathering. Activation required a triggering condition combined with the framing of digital upskilling as shared professional work. In the Nonformal Teacher Professional Learning Community Digital Initiative, Kabupaten Bekasi (urban-industrial context), activation was structurally mediated. Participation was initiated through coordinated leadership that positioned digital competence as a professional necessity. Meetings were formally organized, communication channels were structured, and participation gained administrative recognition. This structural anchoring stabilized engagement early and transformed individual interest into collective obligation.

In the Nonformal Teacher Professional Learning Community Collaborative Learning Community, Kabupaten Tasikmalaya (semi-rural context), activation emerged through reflective structuring. Teachers initially gathered to discuss uncertainty about digital tools and classroom integration. Recurring dialogue gradually evolved into organized collaboration. Here, shared pedagogical concern functioned as the activation trigger, demonstrating that reflective uncertainty can generate structured professional engagement even in moderately resource-constrained settings.

In the Nonformal Teacher Professional Learning Community Digital Innovation Network, Kota Bogor (suburban context), activation was motivationally ignited. Exposure to innovation workshops stimulated enthusiasm among a core group of teachers. Early participation was experimentation-driven before becoming routinized. Affective energy-initiated engagement, but sustainability required eventual structural consolidation. Across cases, activation depended on leadership mediation—formal or emergent—and collective reframing of digital competence as shared responsibility. Cross-case comparison indicates that Bekasi relied more on formal coordination, Tasikmalaya on reflective dialogue, and Bogor on motivational triggers, highlighting context-specific activation pathways.

4.2 Artefact-Mediated Collaborative Practice (RQ1)

This subsection further addresses Research Question 1 by identifying the collaborative mechanisms that operationalize digital upskilling after activation. The objective was to determine how collaborative routines translate participation into concrete competence development.

A central finding across sites is that collaborative digital upskilling was sustained through artefact-mediated inquiry, with AI workshops functioning as the dominant catalytic mechanism. Rather than remaining discussion-based, PLC interaction became structured around shared experimentation and artefact production. Observation data showed that sessions frequently involved real-time co-editing of lesson materials and AI-generated outputs. In Bekasi, AI workshops focused on prompt design, AI-assisted lesson planning, and automated assessment drafting. These sessions transitioned into co-design cycles where teachers contextualized AI-generated materials. AI artefacts thus anchored collaborative production. In Tasikmalaya, workshops emphasized adaptive AI use within infrastructural constraints.

Teachers experimented with simplified content generation and locally relevant materials. AI reduced technological complexity and lowered participation barriers. In Bogor, AI workshops stimulated innovation-oriented experimentation. Teachers tested AI media production and automated feedback tools, followed by peer critique and revision. AI artefacts operated as shared boundary objects organizing inquiry. Across contexts, artefact-centered collaboration shifted PLC interaction from verbal exchange to production-based inquiry, strengthening sustainability. Document analysis confirmed iterative modification of artefacts, with multiple versions of lesson plans reflecting ongoing refinement.

4.3 Iterative Reflection and Feedback Loops (RQ2)

This subsection addresses Research Question 2, which investigates how iterative processes sustain digital competence development over time. The objective was to identify recurring feedback mechanisms that reinforce instructional refinement. Findings indicate that sustained digital competence development depended on iterative reflection mechanisms embedded within collaborative routines. Reflection occurred not as isolated evaluation sessions but as recurring feedback loops linking experimentation and revision. Interview participants described these processes as “continuous adjustment based on classroom feedback.”

Across sites, teachers described reflection cycles involving discussion of implementation experiences, identification of classroom challenges, and modification of digital materials. Observations documented reflection-in-action during workshops, where participants adjusted prompts or lesson outputs collectively. In several sessions, teachers implemented revised materials in classrooms and returned with feedback, forming informal 3R cycles (review, revise, reapply). These iterative loops strengthened instructional alignment and reinforced collective learning continuity. Reflection functioned as a stabilizing mechanism rather than a concluding activity.

4.4 Participation Shift and Role Repositioning (RQ4)

This subsection contributes to Research Question 4 by examining how participation trajectories evolve within non-formal PLCs. The objective was to determine whether sustained engagement produces role transformation and distributed leadership patterns.

Longitudinal patterns reveal progressive participation shifts within the PLCs. Members frequently moved from peripheral observation to active contribution and, in some cases, facilitative roles. Interview data indicated increased confidence and willingness to lead sessions over time. Initially, several teachers attended workshops as observers. Over time, repeated engagement increased confidence in digital experimentation. Participants began sharing classroom adaptations, demonstrating tools, and supporting peers. In Bekasi and Bogor particularly, experienced members assumed informal mentoring functions. This repositioning reflects distributed leadership dynamics within non-formal PLC structures. Participation shift was strongly associated with artefact production; teachers who co-developed materials were more likely to transition into facilitative roles.

4.5 Contextual Conditions and Stability (RQ3)

This subsection directly addresses Research Question 3, which explores the contextual conditions enabling or constraining sustainability. The objective was to identify environmental and structural stabilizers that influence recurring PLC mechanisms.

Sustainability of PLC activity was shaped by contextual stabilizers rather than uniform institutional support. Four primary conditions emerged: infrastructure reliability, time allocation, leadership continuity, and intrinsic motivation. Infrastructure influenced the complexity of digital experimentation, particularly in Tasikmalaya. Time allocation determined participation consistency across all sites. Leadership continuity provided coordination stability in Bekasi and Bogor. Intrinsic motivation sustained voluntary engagement even in the absence of formal mandates. Despite contextual differences, stability was achieved when at least two of these conditions were present simultaneously.

For example, in Tasikmalaya, strong intrinsic motivation compensated for limited infrastructure, whereas in Bekasi, structured leadership and time allocation were dominant stabilizers. Where infrastructure was limited, strong motivation and leadership compensated. Where motivation fluctuated, structured scheduling reinforced continuity. Collectively, these findings demonstrate that non-formal PLC sustainability operates through recurring mechanisms – activation, artefact-mediated inquiry, iterative reflection, participation repositioning, and contextual stabilization – rather than through fixed organizational structures.

4.6 Cross-Sectional Synthesis and Alignment with Research Objectives

Taken together, the results provide a coherent and mechanism-based response to the three research questions. Research Question 1 is addressed through the identification of differentiated activation pathways and artefact-mediated collaborative routines, demonstrating that non-formal PLC initiation and

operationalization are structured by leadership framing and production-centered inquiry rather than spontaneous interaction. Research Question 2 and 4 are answered through evidence of iterative reflection cycles and progressive participation repositioning, indicating that sustainability emerges from recurring feedback loops and distributed role transformation. Research Question 3 is resolved through the identification of contextual stabilizers—specifically infrastructure reliability, time allocation, leadership continuity, and intrinsic motivation—showing that stability depends on the interaction of structural and motivational conditions.

Across sites, convergence of activation triggers, artefact production density, reflection recurrence, and role transition patterns indicates strong cross-case replication. At the same time, variations in activation modes, resource availability, and leadership structures highlight context-specific adaptations of the same underlying mechanisms. The analytical strength of these results lies in demonstrating patterned mechanism operation rather than isolated contextual description. Non-formal PLCs function as dynamic process systems in which initiation, collaborative production, reflective refinement, and contextual reinforcement interact to sustain digital competence development over time. These mechanism-based findings establish the empirical foundation for the theoretical integration presented in the subsequent discussion section.

5. Discussion

5.1 Reinterpreting PLC Through a Process Lens

The findings reposition the PLC in non-formal teacher networks from a static organizational “structure” to a set of recurring, generative mechanisms that reproduce collaboration over time. This process lens aligns with scholarship showing that PLC emergence and sustainability are not guaranteed by establishing meetings or platforms, but depend on the interplay of leadership dynamics, professional connectedness, trust-based social relationships, enabling conditions, and motivational resources that activate and sustain collective work (Sharimova & Wilson, 2025).

In voluntary or non-formal contexts, professional connectedness functions as a relational driver: teachers seek collegial exchange to mitigate isolation and to access practical mentoring and planning support, particularly when geographic distance or uneven resources constrain day-to-day professional interaction (Sharimova, 2025). The present study extends this view by demonstrating that connectedness is operationalized through repeatable sequences—activation framing, artefact-mediated inquiry, iterative reflection, and role repositioning—rather than through formal membership alone. This finding moves beyond prior PLC research that primarily identifies enabling conditions by explaining how those conditions are enacted through recurring collaborative processes.

This mechanism-based interpretation also clarifies why PLC implementation can remain episodic when treated primarily as a structural program. Prior work emphasizes that leadership, motivation, and structural reorganization operate synergistically to move PLCs beyond temporary initiatives toward

institutionalized practice (Olmo-Extremera et al., 2024). The results show that in non-formal PLCs, “structural reorganization” is enacted less through policy mandates than through emergent routines that stabilize participation: scheduled collaboration, clear facilitation roles, shared norms for contribution, and the availability of artefacts that make professional practice discussable and improvable (Huijboom et al., 2023). Accordingly, PLC effectiveness should be interpreted as a function of mechanism recurrence and coupling (i.e., the degree to which initiation, co-design, implementation, and reflection are linked), not merely the presence of PLC labels or meeting frequency. This interpretation is particularly important in resource-variable contexts, where sustainability depends less on formal structures than on the continuity of collaborative routines.

5.2 The Community-Based Digital Upskilling Cycle (CBDUC)

To integrate these process findings into an explanatory model, this study proposes the Community-Based Digital Upskilling Cycle (CBDUC), a six-stage mechanism sequence that captures how voluntary PLCs convert initial engagement into sustained digital competence development. Unlike existing PLC models that emphasize structural dimensions or general collaborative features, CBDUC specifies the sequential mechanisms through which participation becomes stabilized, redistributed, and extended over time.

Stage 1: Initiation. Initiation is triggered by a shared professional need for connectedness and by teachers’ belief that they can contribute meaningfully to collective knowledge-building. Empirical activation pathways observed across sites are consistent with research emphasizing relational connectedness, knowledge-sharing self-efficacy, and trust as foundational activation conditions (Sharimova & Wilson, 2025). Leadership is catalytic at this stage, particularly when distributed leadership roles help cultivate shared values and collaborative norms (Wang & Bush, 2025). External reform signals can further legitimize initiation by creating perceived urgency and alignment with broader professional expectations (Hsieh et al., 2025).

Stage 2: Co-design. Co-design describes the collaborative translation of shared needs into tangible instructional solutions. In CBDUC, co-design is sustained through shared artefacts that anchor dialogue and scaffold collective inquiry. This is supported by literature demonstrating that shared artefacts—lesson plans, digital tools, and instructional materials—function as epistemic anchors that deepen professional dialogue and move collaboration beyond superficial exchange (Órdenes Guzmán et al., 2025). In the present study, AI-supported workshops intensified this stage by accelerating the production of draft materials for collaborative refinement, rather than replacing teacher judgment. Digital platforms and groupware facilitate co-design by enabling real-time or asynchronous negotiation of pedagogy, content, and assessment (Órdenes Guzmán et al., 2025).

Stage 3: Implementation. Implementation refers to the enactment of co-designed artefacts in classroom practice and the production of practice-based evidence for collective review. This stage is strengthened when artefacts are designed to invite

adaptation rather than compliance. Prior work cautions that while shared artefacts build professional skills, overreliance on ready-made resources may constrain critical thinking and innovation; therefore, implementation must preserve teacher agency and iterative experimentation (Lazareva & Tømte, 2024). The present findings refine this insight by highlighting AI workshops as high-leverage implementation catalysts: they intensify experimentation density and accelerate the conversion of ideas into classroom-ready materials.

Stage 4: Reflection. Reflection is conceptualized as a structured, recurring feedback mechanism embedded within PLC routines rather than a terminal evaluation. This aligns with evidence that public and collaborative reflection can function as continuous professional development, sustaining instructional change beyond isolated training events (Bondurant, 2024). Reflection depth is strengthened by tools such as video-stimulated recall and guided prompts, which support analytic examination of instructional decisions and lead to adaptive practice (Çolak & Koçoğlu, 2025). Feedback-driven cycles—peer observation, reciprocal peer discourse, and structured meeting protocols—further institutionalize iterative improvement (Flores et al., 2025).

Stage 5: Transformation. Transformation refers to sustained shifts in professional roles, identities, and leadership distribution that emerge as participation becomes more consequential and responsibility becomes shared. The findings' participation trajectories correspond with scholarship showing that teachers' roles evolve over time from peripheral participation to active collaboration and, ultimately, to distributed leadership when trust and shared routines stabilize (Eylon et al., 2020). Trust-based environments enhance openness, vulnerability, and willingness to share dilemmas—conditions that support deeper inquiry and professional identity consolidation (Valckx et al., 2018). In this stage, PLCs become vehicles for agency and resilience, linking collaborative engagement to more durable professional commitments (Özer & Çelik, 2024).

Stage 6: Diffusion. Diffusion captures how artefacts, routines, and leadership practices extend beyond the original community, strengthening network viability and broadening access to resources. Inter-school or cross-institutional networks expand professional learning capacity and support professionalization across settings, especially when network quality and intentionality are high (Liou et al., 2025). Technology-enabled platforms further facilitate diffusion by lowering barriers to sharing and enabling asynchronous participation across distance and time constraints (Le et al., 2024). However, diffusion is constrained when feedback timing, workload distribution, and coordination norms are not managed, indicating the need for facilitation and clear collaboration protocols (Órdenes Guzmán et al., 2025). The model should therefore be understood as most applicable where at least minimal coordination, artefact-sharing capacity, and recurrent participation can be sustained.

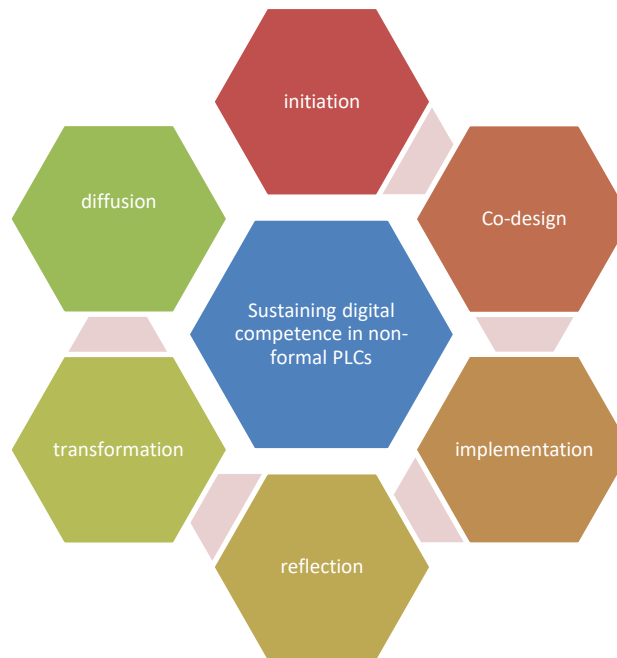


Figure 1: Community-Based Digital Upskilling Cycle (CBDUC) Model

The CBDUC model represents a cyclical, mechanism-based process rather than a linear program. Initiation activates participation; co-design generates shared artefacts; implementation enacts artefacts in classroom practice; reflection produces structured feedback for refinement; transformation stabilizes distributed leadership and professional identity; and diffusion extends artefacts and routines across broader networks, regenerating subsequent co-design cycles. At the same time, the cycle is not assumed to unfold uniformly across all contexts; stages may vary in intensity depending on infrastructure, leadership continuity, and participant motivation.

5.3 Theoretical Implications

For PLC scholarship, CBDUC contributes a process-explicit account of how non-formal PLCs operate as mechanism systems. The model clarifies that leadership is not merely a contextual “enabler” but a catalytic mechanism that couples participation with shared purpose, routines, and accountability (Wang & Bush, 2025). It also advances the understanding of relational foundations—trust, belonging, and reflective dialogue—as operational pathways that increase the depth and durability of collaboration, not simply desirable climate features (Hauge & Wan, 2019). Finally, CBDUC provides a mechanism-based bridge between structural and agency-oriented explanations by showing how participation produces distributed leadership and role evolution through repeated cycles of artefact work and feedback (García-Martínez et al., 2018). In this way, the model extends prior PLC scholarship by shifting the analytic focus from structural attributes to recurrent process mechanisms.

For digital competence research, the model strengthens the argument that competence development is sustained when digital learning is embedded in artefact-mediated co-design and iterative feedback rather than in isolated

training. Shared artefacts externalize practice, make instructional decisions discussable, and enable cumulative refinement – thereby supporting competence growth as a socially distributed, practice-based process (Basque et al., 2025). The model also highlights the potential and limits of AI-supported artefact production: AI can accelerate production and broaden access to design supports, but sustained competence requires feedback literacy, reflective routines, and agency-preserving adaptation to avoid superficial or compliance-driven uptake (Afrilyasanti et al., 2026).

For non-formal professional learning, CBDUC clarifies how voluntary networks can sustain engagement through motivational and identity resources. Evidence linking PLC participation to teacher confidence, well-being, and job satisfaction implies that motivation is both an input and an outcome of sustained collaboration (Olmo-Extremera et al., 2024). The present findings further suggest that extrinsic recognition and institutional acknowledgment can complement intrinsic commitment by stabilizing participation in contexts where time and workload pressures threaten continuity (Sivaraja et al., 2025). Thus, non-formal PLC sustainability is best theorized as the coupling of relational connectedness, purpose framing, artefact work, and feedback routines within supportive structural conditions. This contribution is especially relevant for voluntary teacher networks in contexts where formal institutional support is uneven or limited.

5.4 Policy Implications

First, infrastructure policy should be conceptualized as an enabling ecosystem rather than a single resource provision. Studies consistently show that digital divides—in devices, connectivity, and accessibility tools—undermine participation continuity and weaken the broader professional learning ecology (Sadiki & Mahetlana, 2025). Policies should therefore prioritize baseline connectivity reliability, shared access points, and support for inclusive digital participation, particularly in resource-variable environments. Second, time allocation must be treated as a governance commitment. Even highly motivated PLCs struggle when collaboration time is not protected. Evidence indicates that structured collaboration time and coherent meeting routines are indispensable for PLC development and sustainability (Huijboom et al., 2023).

Policy levers include integrating PLC participation into workload models, legitimizing collaboration within professional standards, and reducing opportunity costs for teachers. Third, artefact diffusion should be strengthened through designed sharing infrastructures and norms. Digital platforms can enable asynchronous sharing and broaden participation across schools, but diffusion requires facilitation to manage coordination burdens and to maintain feedback quality (Órdenes Guzmán et al., 2025). Policy support should therefore include repository design, lightweight documentation templates, and facilitation guidelines that encourage adaptation, not simply replication. Fourth, coordinative roles should be formally supported as part of distributed leadership capacity. Research demonstrates that teacher leaders and high-influence brokers strengthen cohesion, protect inquiry norms, and sustain participation quality, particularly in

online or hybrid communities (Wang & Bush, 2025). Policy mechanisms may include recognition pathways, micro-credentials for facilitation expertise, and targeted leadership development to sustain the CBDUC stages—especially co-design, reflection, and diffusion. These implications are particularly relevant to Indonesian and similar resource-variable educational settings, where voluntary teacher communities often compensate for uneven formal professional development provision. Overall, the discussion demonstrates that non-formal PLCs sustain teachers' digital competence development when recurring mechanisms—initiation, co-design, implementation, reflection, transformation, and diffusion—are coupled with enabling infrastructures, protected time, artefact-sharing systems, and supported coordinative leadership. The CBDUC model provides a transferable process framework for designing and evaluating sustainable digital upskilling in voluntary teacher professional communities.

6. Conclusion

This study reconceptualizes non-formal Professional Learning Communities (PLCs) as recurring mechanism systems rather than static organizational structures. Drawing on a multi-site case study, the findings demonstrate that sustainable digital competence development emerges through a cyclical sequence of activation, collaborative co-design, artefact-mediated implementation, structured reflection, role transformation, and network diffusion. These findings directly address the research questions by showing how non-formal PLCs operationalize collaborative principles, the mechanisms through which participation becomes sustained, and the contextual conditions shaping their stability. Rather than being sustained by formal mandates alone, non-formal PLCs stabilize through relational trust, distributed leadership, shared artefact production, and iterative feedback routines.

In addition, AI-supported tools function as accelerators that enhance artefact production and iterative experimentation within these processes. The proposed Community-Based Digital Upskilling Cycle (CBDUC) model integrates these mechanisms into a coherent explanatory framework. The model contributes a process-explicit explanation that distinguishes this study from prior PLC frameworks that primarily emphasize structural characteristics or outcome indicators. Theoretically, this study contributes to PLC scholarship by advancing a process-explicit interpretation that links leadership, motivation, and structural conditions to recurring collaborative mechanisms. It further extends PLC theory to non-formal and resource-variable contexts, which remain underexplored in existing literature. It extends digital competence research by demonstrating that artefact production and iterative reflection function as mediating pathways between professional learning and sustained instructional transformation.

The findings also highlight the conditional role of AI as a catalyst, whose effectiveness depends on access, teacher readiness, and contextual support. For non-formal professional learning contexts, the study highlights how voluntary networks can generate durable professional identity shifts and distributed leadership patterns when supported by enabling infrastructures. Practically, the findings underscore the importance of reliable digital infrastructure, protected

collaboration time, facilitative leadership roles, and structured artefact-sharing systems. These implications are particularly relevant for educational systems such as Indonesia, where non-formal teacher networks play a critical role in complementing formal professional development structures. Policies that support these conditions are more likely to produce sustained professional growth rather than episodic innovation. This study is limited by its qualitative design and contextual specificity, which constrain statistical generalizability. Additionally, the study is bound by the scale of three PLC cases and relies on self-reported and observational data, which may not fully capture long-term instructional impact.

Future research should employ longitudinal and mixed method approaches to test the CBDUC model across diverse educational systems and to examine its impact on measurable instruction and student outcomes. Future studies should also examine the boundary conditions of the model, including variations in infrastructure, participation continuity, and leadership capacity, as well as the evolving role of AI as an accelerator in different educational contexts. Expanding investigation into AI-supported collaborative artefact production also represents a promising direction for further inquiry.

Conflict of Interest

The authors declare no conflict of interest.

7. Acknowledgments

The authors wish to acknowledge the use of Chat GPT in the writing of this paper. This tool was used to help improve the language and grammar in the paper. The paper remains an accurate representation of the authors' work and intellectual contributions.

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