



Enhancing Collegial Supervision and Deep Learning Practices through TPACK-Based Professional Development in Early Childhood Education

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Abstract

The integration of technology, deep learning pedagogy, and collaborative leadership remains a challenge for early childhood education (ECE) institutions in rural Indonesia, where limited resources and fragmented professional development often constrain instructional innovation. This study examined an integrated professional development program designed to strengthen principals' collegial supervision competencies and teachers' implementation of deep learning through the Technological Pedagogical and Content Knowledge (TPACK) framework. A mixed-methods participatory action research design with a one-group pre-post assessment was employed involving 40 participants (20 principals and 20 teachers) from 20 ECE institutions in Karangpawitan District, Garut Regency, Indonesia. The two-month program combined online training, face-to-face workshops, mentoring, classroom implementation, and follow-up evaluation. Quantitative data were collected using validated TPACK, Collegial Supervision, and Deep Learning instruments, while qualitative data were obtained through observations and semi-structured interviews. Pre-post comparisons indicated improvements in teachers' TPACK competencies (Cohen's $d = 3.24$) and principals' collegial supervision competencies ($d = 2.98$). Classroom observations and participant reflections further suggested positive changes in the implementation of deep learning practices, including greater use of inquiry-based learning, reflective activities, and purposeful technology integration. Follow-up evaluation indicated that most participants maintained the competencies developed during the program. These findings suggest that an integrated and context-responsive professional development approach may support the development of pedagogical, technological, and leadership capacities in rural ECE settings. The program also provides a practical framework for fostering collaborative professional learning and strengthening instructional improvement in resource-constrained educational contexts.

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INTRODUCTION

Early childhood education (ECE) in Indonesia, particularly in rural areas, faces increasing demands to provide meaningful learning experiences while integrating digital technologies into classroom practice. Although technology-supported and inquiry-oriented approaches have gained attention in recent years, many ECE institutions continue to experience challenges in implementing these approaches effectively. Limited technological infrastructure, unequal access to digital resources, and insufficient professional development opportunities often constrain teachers' ability to integrate technology in pedagogically meaningful ways (Lim & Wardrip, 2024). These challenges highlight the need for professional development initiatives that not only strengthen technological competencies but also support teachers in designing learning experiences that promote inquiry, reflection, and deeper understanding among young learners.

This initiative contributes to the United Nations Sustainable Development Goal (SDG) 4 on Quality Education, particularly Target 4.c and Target 4.7. Through TPACK-informed professional development, collegial supervision, and follow-up mentoring, the program strengthened teachers' and principals' professional capacities, directly supporting Target 4.c, which emphasizes increasing the supply of qualified teachers through professional development (United Nations, 2015). At the classroom level, the implementation of technology-supported and deep learning practices promoted more innovative, meaningful, and inclusive learning experiences for young children, thereby contributing to Target 4.7 and the broader goal of equitable and high-quality education (Lim & Wardrip, 2024).

Karangpawitan District in Garut Regency provides an illustrative context for these challenges. Similar to many rural ECE communities in Indonesia, institutions in this area face limited familiarity with deep learning pedagogy, continued reliance on evaluative supervision practices, and varying levels of readiness to adopt innovative instructional approaches. A previous training needs analysis conducted in the same district Nurillah et al. (2025) identified substantial professional development needs related to teachers' Technological Pedagogical and Content Knowledge (TPACK) competencies. The findings of that study informed the design of the present professional development program by identifying priority areas for teacher and principal capacity building. However, the current study constitutes a separate intervention and evaluation project, involving a new cycle of data collection and analysis focused on the implementation of collegial supervision and deep learning practices.

The needs assessment also highlighted a mismatch between teachers' intentions to adopt more meaningful and innovative learning practices and the conditions that support such efforts. While many teachers expressed interest in integrating technology and student-centered approaches, they also reported challenges related to supervision practices, limited access to technological resources, and insufficient opportunities for sustained professional learning. Similar challenges have been documented in other rural educational contexts, where teachers' efforts to adopt innovative instructional practices are often influenced by both individual and institutional factors (Xu, 2024). These findings suggest that improving instructional practice requires attention not only to teachers' competencies and motivation but also to the broader organizational conditions that support educational change.

Despite the growing body of research on professional development in early childhood education, several important gaps remain. Previous studies have examined TPACK, collegial supervision, and deep learning as largely separate areas of inquiry, with relatively limited attention to how these approaches may be integrated within a single professional development framework (Jiménez-Sierra et al., 2023; Leung et al., 2024; Mishra & Koehler, 2006; Naik et al., 2020; Strieker et al., 2016). This fragmented focus limits understanding of how teacher competencies, leadership support, and pedagogical implementation can be developed simultaneously within a coherent professional development process. While some professional development initiatives have explored multiple dimensions of teacher capacity building, evidence regarding the integration of TPACK, collegial supervision, and deep learning remains limited, particularly in rural ECE contexts. Furthermore, research examining collaborative interventions involving both principals and teachers is still relatively scarce in the Indonesian ECE sector. Therefore, this study seeks to

contribute to the literature by developing and evaluating a context-sensitive professional development model for rural early childhood education institutions.

Collegial supervision represents an alternative approach to educational leadership compared with the more traditional supervisory practices commonly experienced by principals in rural Indonesian schools (Kareem et al., 2023). Rather than positioning the principal primarily as an evaluator of compliance, collegial supervision emphasizes shared vision, reflective practice, and collaborative decision-making within the school community (Sliwka et al., 2024). This approach is particularly suitable for rural ECE settings, where limited resources and close working relationships require context-sensitive, collaborative support rather than predominantly directive supervision. Dikdik et al. (2024) found that this democratic and collaborative approach, in which principals work alongside teachers rather than solely directing them, aligns well with the values of participation and collective responsibility that characterize many educational settings in Indonesia.

Previous studies consistently show that collegial and collaborative supervision positively influences teachers' professional development, although they emphasize different aspects. Wiyono et al. (2021) highlighted its role in improving teachers' implementation of performance-based learning, while Nurbani et al. (2025) emphasized principals' collaborative leadership in supporting curriculum development. Likewise, Fariha et al. (2025) found that collaboration-based training is more effective than conventional approaches in strengthening pedagogical competence. Collectively, these studies suggest that collaboration and shared leadership are essential for sustainable professional development. However, they have largely examined these approaches independently, with limited attention to their integration with TPACK and deep learning in rural early childhood education contexts.

In this study, deep learning refers to a pedagogical approach that promotes meaningful engagement with learning through inquiry, reflection, collaboration, and the active construction of knowledge. Rather than focusing on the transmission of information, deep learning encourages learners to connect new ideas with prior experiences, solve authentic problems, and apply their understanding in meaningful contexts. This perspective is consistent with contemporary views of deeper learning, which emphasize critical thinking, creativity, communication, collaboration, reflective practice, and meaningful knowledge construction as key dimensions of effective learning experiences. These dimensions also informed the observation indicators used in the present study to assess the implementation of deep learning practices in ECE classrooms.

The TPACK framework, developed by Mishra & Koehler (2006), provided the conceptual and operational foundation for technology integration in the training program, with its seven components addressed through activities combining ECE content, pedagogical strategies, and digital technology. Participants applied these components through hands-on development and implementation of technology-supported learning activities, allowing TPACK to guide both the training process and its classroom application. In the ECE context specifically, Park & Hargis (2018) argued for recognizing an affective dimension within TPACK, acknowledging that teachers' emotions and values shape how they engage with technology. Effective TPACK implementation also requires leadership. Dikdik et al. (2024) found that school-based digital leadership contributes to innovation and positive change through thoughtful application of technology. More recently, Leung et al. (2024) observed that preservice ECE teachers concentrated heavily on PCK and TCK during digital storytelling activities, while TPK, the intersection of technology and pedagogy, received less attention and warrants further development.

Blended learning has become an increasingly attractive format for ECE professional development, particularly in contexts where educators cannot easily leave their classrooms for extended periods. Pölzl-Stefanec et al. (2024) highlighted how co-constructivist online programs can advance professionalization in ways that are cost-effective and flexible. The evidence on outcomes is also encouraging: a meta-analysis by Egert et al. (2020) found a meaningful effect size ($g = 0.39$) for professional development programs in improving educator-child interaction quality, suggesting that flexible professional development formats can deliver meaningful pedagogical gains. These findings informed the design of the present program, which adopted a blended learning structure combining online training sessions with school-based implementation, face-to-face or contextualized support, and follow-up mentoring. This design was intended to provide flexibility for rural ECE educators while maintaining opportunities for practical application,

feedback, and sustained professional support during the implementation of TPACK and deep learning practices.

This study contributes to the literature in three ways. First, it examines an integrated professional development model that combines collegial supervision, deep learning pedagogy, and the TPACK framework within a single intervention. Second, it extends existing research by exploring the implementation of this model in rural early childhood education settings, where access to professional development opportunities and technological resources is often limited. Third, it investigates how collaborative engagement between principals and teachers may support instructional improvement and professional learning.

Accordingly, this study aimed to: (1) examine changes in principals' collegial supervision competencies following participation in the professional development program; (2) examine changes in teachers' TPACK competencies; and (3) explore participants' experiences in implementing deep learning practices within rural ECE settings. To support technology integration during the training activities, participants were introduced to several digital tools, including Canva, as practical resources for developing instructional materials. Canva was selected as one of the supporting tools because previous research has highlighted its potential to facilitate the development of visually engaging learning materials and support teachers' digital technology integration in educational contexts (Susanah et al., 2025).

Theoretically, this study extends the application of the TPACK framework by integrating collegial supervision and deep learning within a professional development approach tailored to rural ECE contexts. Practically, the study provides insights that may inform policymakers, school leaders, and teacher education providers in designing professional development initiatives that support technology integration, collaborative supervision, and instructional improvement in resource-constrained educational settings.

METHOD

This study employed a mixed-methods participatory action research (PAR) design, combining a one-group pretest-posttest quantitative component with qualitative data from observations, interviews, and participant reflections. (Sendall et al., 2018; Wallerstein & Duran, 2010; Connell et al., 2017) The quantitative component was used to examine changes in teachers' TPACK competencies and principals' collegial supervision competencies before and after the professional development program, while the qualitative component explored participants' experiences and the implementation of deep learning practices during the intervention (Kareem et al., 2023; Ghamrawi et al., 2024). The two strands were integrated during interpretation to provide a more comprehensive understanding of the observed changes and participants' experiences. The study did not include a control group or randomization; therefore, pre-post changes are interpreted as associations observed following the intervention rather than as evidence of causal effects (Sliwka et al., 2024). Participants were engaged as active contributors to the professional development process, consistent with the participatory orientation of PAR. The PAR procedures and stages implemented in the study are presented in Figure 1.

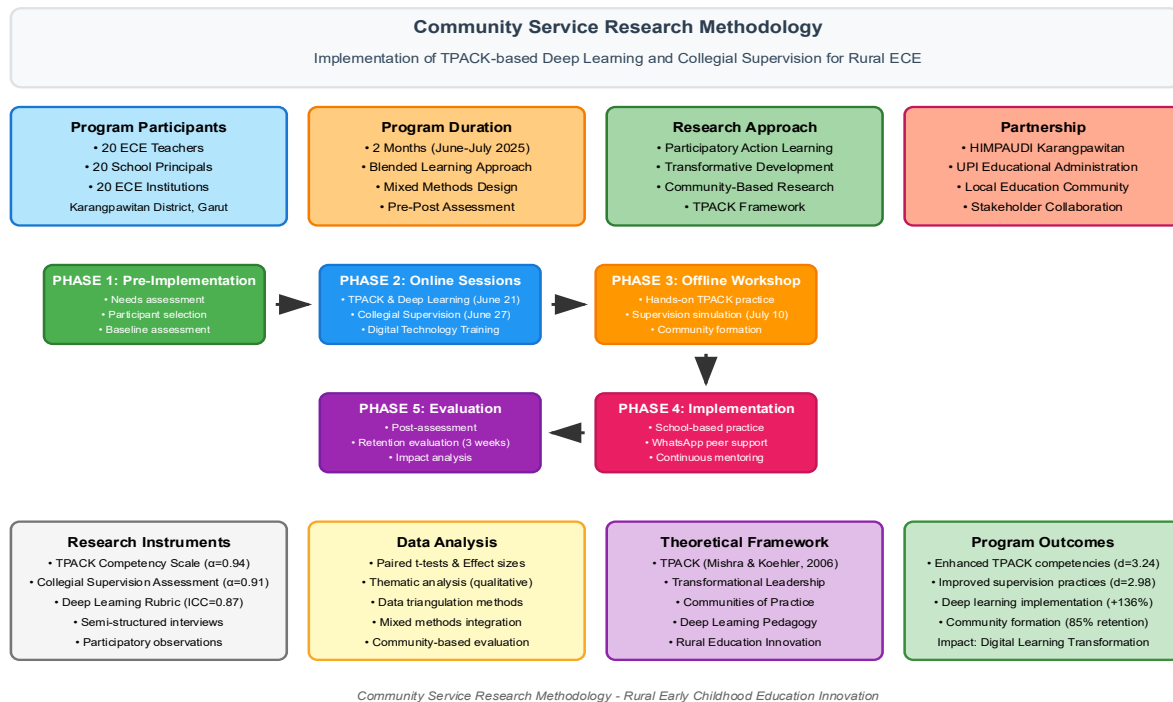


Figure 1. Flow of Research Methodology and Program Implementation

The theoretical underpinning of this program draws on three interrelated frameworks. TPACK provided the organizing framework for teacher development, given its demonstrated utility in early childhood education (ECE) settings and its adaptability to resource-constrained rural contexts (Chuang & Ho, 2011). Transformational leadership theory, as conceptualized by Bass & Riggio (2006), shaped our approach to principal development, based on the understanding that teachers function as learning leaders with a strategic role in educational transformation (Dikdik et al., 2025), and that strengthening teachers' TPACK competencies necessitates a parallel shift in how principals lead. Finally, Communities of Practice, drawing on Warr Pedersen (2017) provided the model for sustainability by recognizing that lasting change requires professional networks that extend beyond any single training event. Together, these frameworks informed an integrated intervention design in which TPACK strengthened teachers' pedagogical and technological competencies, transformational leadership supported principals in creating an enabling environment for teachers' professional growth, and Communities of Practice facilitated ongoing collaboration and knowledge sharing to sustain the implementation of these competencies beyond the formal training period.

Before any training began, the research team conducted thorough fieldwork to understand the actual conditions of deep learning practice in Karangpawitan institutions. This involved systematic site visits and discussions with key stakeholders. The assessment process included semi-structured interviews with principals, teachers, and HIMPAUDI administrators, designed to surface the specific challenges they faced with deep learning implementation, the pedagogical goals they were working toward, and the resources already available to them. This groundwork shaped everything that followed.

Participant selection used purposive sampling with maximum variation as the guiding principle, seeking diversity in geographic location, institutional profile, teaching and leadership experience, and digital literacy. This sampling strategy was chosen to capture the diversity of rural ECE contexts and participant characteristics, thereby enabling the professional development program to be evaluated across varying institutional conditions and enhancing the transferability of the findings. The final sample comprised 40 participants, including 20 teachers and 20 principals from 20 separate ECE institutions. This sample size was considered appropriate for the program evaluation because the pre-post design enabled within-participant comparisons of changes following the intervention, while the inclusion of participants from 20 different institutions provided variation in institutional and contextual characteristics. The sample size was also feasible

for the intensive blended training, school-based implementation, and follow-up mentoring components of the program. Inclusion criteria required active teachers with at least two years of classroom experience, principals with at least one year in their role, basic technology access (smartphone or tablet), willingness to complete the full program, and informed consent to participate in the study. The demographic characteristics of the participants are presented in Table 1.

Table 1. Demographic Characteristics of Program Participants

Characteristics	Teacher (n=20)	Principal (n=20)
Average age	45	55
Age range	40-50	50-60
Gender		
- Male	-	1 (5%)
- Female	20 (100%)	19 (95%)
Last Education		
- Senior High School	17 (85%)	9 (45%)
- Bachelor	3 (15%)	11 (55%)
- Magister	-	-
Work Experience		
- < 5 years	2 (10%)	2 (10%)
- 5-10 years	6 (30%)	4 (20%)
- > 10 years	12 (60%)	14 (70%)
Institution Status		
- Public	-	-
- Private	20 (100%)	20 (100%)
Internet Access		
- Stable	20 (100%)	20 (100%)
- Unstable	-	-
- None	-	-
Digital Literacy Level		
- High	-	-
- Medium	20 (100%)	20 (100%)
- Low	-	-

Three previously validated instruments were adapted to the rural early childhood education (ECE) context in Indonesia to collect quantitative data. The adaptation process involved contextual modification of the original items while maintaining the underlying constructs and item structure, followed by content validation by three experts in early childhood education and educational management and a pilot test to assess item clarity, contextual appropriateness, and response consistency. The TPACK Competency Scale (TCS), adapted from [Schmidt et al., \(2009\)](#), assessed teachers' TPACK competencies using 35 items across the specified TPACK domains on a five-point Likert scale (Cronbach's $\alpha = 0.94$). The Collegial Supervision Assessment (CSA), adapted from [Strieker et al. \(2016\)](#), measured principals' collegial supervision competencies using 30 items across five dimensions on a five-point Likert scale (Cronbach's $\alpha = 0.91$). The Deep Learning Implementation Rubric (DLIR), adapted from [Fullan & Langworthy \(2014\)](#) and informed by structured classroom observation principles, assessed the implementation of deep learning practices using descriptive performance levels and a corresponding rating scale. The DLIR was independently scored by three lecturers using the same rubric and scoring criteria. The raters reviewed the rubric before conducting the assessment, and each rater independently evaluated the observed implementation of deep learning practices. Inter-rater reliability was assessed using the Intraclass Correlation Coefficient (ICC = 0.87).

The program unfolded over two months (June–July 2025) using a blended learning structure. The first online session (Saturday, June 21, 2025) introduced collegial supervision concepts and deepened participants' understanding of deep learning implementation. The second online session (Friday, June 27, 2025) introduced the TPACK framework specifically for ECE contexts. This was followed by an intensive face-to-face session (Thursday, July 10, 2025) providing hands-on practice and guided implementation. Following the formal training sessions, participants implemented TPACK-based deep learning practices in their respective schools. To support implementation, participants received ongoing monitoring through a dedicated WhatsApp group that facilitated consultation, discussion, and technical support. In addition, individual feedback was provided

based on participants' assessment results and implementation tasks, while follow-up mentoring was conducted by facilitators to assist participants in refining instructional practices, digital learning media, and collegial supervision instruments. The implementation of the professional development program is illustrated in Figure 2 through photographs documenting the major activities conducted during each stage of the intervention.



Figure 2. Documentation of a Series of Online and Offline Training Activities that Strengthened Collegial Supervision Practices and The Implementation of Deep Learning through the TPACK Approach and The Use of Canva for Early Childhood Education Principals and Teachers

The atmosphere of the offline community service activity during which Early Childhood Education teachers presented TPACK-based lesson plans and developed instructional materials using Canva. The session also included structured reflection and the sharing of good practices to foster a community of practice that supports ongoing professional development.

Data collection combined quantitative and qualitative methods. Quantitative data were collected using pre-test assessments administered before the commencement of the program and post-test assessments conducted after the completion of the intensive offline workshop. The TCS, CSA, and DLIR instruments were used to measure changes in participants' competencies, supplemented by demographic data, attendance records, and documentation of program implementation. Qualitative data were collected throughout the training and implementation phases. Participatory observations were conducted during the workshop activities and school-based implementation, with systematic field notes documenting learning and supervision processes. Semi-structured interviews were conducted after the training and school implementation phases with all participants, consisting of 20 teachers and 20 principals from 20 ECE institutions. Participants were selected through purposive sampling based on their active involvement in the program, ability to provide reflective accounts of their experiences, and variation in professional backgrounds and experience. Additional qualitative data were obtained from photo and video documentation, artifact analysis of lesson plans and supervision instruments developed by participants, and implementation checklists used during the follow-up evaluation to monitor the sustainability of program practices.

Quantitative analysis relied on paired t-tests to examine pre-post differences, Cohen's *d* to estimate effect sizes, descriptive statistics to summarize participant and implementation characteristics, and correlation analysis to examine the relationships between the study variables (Lakens, 2013). Before conducting the paired t-tests, the normality assumption of the difference scores was assessed using the Shapiro-Wilk test. Given the multiple dimension-level comparisons conducted in the study, the findings were interpreted cautiously by considering both statistical significance and the magnitude of the effect sizes. For qualitative data, reflexive thematic analysis

was applied to interview transcripts, field notes, and participant reflections to identify patterns and develop themes [Byrne \(2022\)](#). The analysis involved several iterative stages: familiarization with the data, generation of initial codes, identification of preliminary themes, review and refinement of themes, definition and naming of themes, and synthesis of the final thematic findings. Triangulation across multiple qualitative data sources, including observations, interviews, field notes, participant reflections, and participant-generated artifacts, was used to strengthen the credibility and consistency of the findings ([Lim, 2025](#)).

RESULTS AND DISCUSSION

Result

The program brought together 40 participants, 20 teachers, and 20 principals from 20 ECE institutions in Karangpawitan District, Garut Regency. The group's composition reflected what is typical of rural Indonesian ECE: an overwhelmingly female workforce (95% of principals, 100% of teachers), with average ages of 45 years for teachers and 55 years for principals. Most teachers came with high school qualifications (85%), while principals showed more varied educational backgrounds (45% high school, 55% bachelor's degree). Every participant worked in a private institution and reported stable internet access, with digital literacy levels assessed as moderate across the board.

Quantitative Results

Statistical analysis of pre-post assessments revealed meaningful gains across all seven TPACK competency dimensions following the training program. The psychometric properties of the research instruments are summarized in Table 2.

Table 2. Results of Pre-Post Assessment of Teachers' TPACK Competency (n=20)

Dimensions TPACK	Pre-test M(SD)	Post-test M(SD)	t- value	p- value	Cohen's d	Interpretations by Lakens (2013)
Technology Knowledge (TK)	2.12(0.73)	4.23(0.45)	16.42	<0.001	3.47	Very Large
Pedagogical Knowledge (PK)	3.45(0.62)	4.56(0.38)	9.87	<0.001	2.12	Large
Content Knowledge (CK)	3.78(0.55)	4.34(0.42)	5.34	<0.001	1.13	Medium
Technological Pedagogical Knowledge (TPK)	2.34(0.68)	4.18(0.47)	14.23	<0.001	3.12	Very Large
Technological Content Knowledge (TCK)	2.45(0.71)	4.02(0.52)	12.87	<0.001	2.65	Large
Pedagogical Content Knowledge (PCK)	3.56(0.59)	4.45(0.41)	8.92	<0.001	1.78	Large
TPACK Total Score	2.45(0.67)	4.12(0.43)	15.23	<0.001	3.24	Very Large

Based on the effect size interpretation criteria described in the methods section following Lakens, Technology Knowledge ($d = 3.47$) and Technological Pedagogical Knowledge ($d = 3.12$) demonstrated the largest effect sizes, indicating that these two TPACK dimensions exhibited the greatest improvement following the training. Qualitative findings from participant reflections and interviews suggested that hands-on activities, collaborative lesson design, and guided practice using digital instructional tools were perceived as valuable components of the program. These experiences may have contributed to participants' development of technology-related competencies, although the present study was not designed to determine the specific contribution of individual program components. To evaluate changes in principals' collegial supervision competencies after the intervention, pretest and post-test assessment results are summarized in Table 3.

Table 3. Results of Pre-Post Assessment of Collegial Supervision Ability of Principal (n=20)

Dimensions of Supervision	Pre-test M(SD)	Post-test M(SD)	t- value	p- value	Cohen's d	Interpretations by Lakens (2013)
Relationship Building	2.56(0.78)	4.23(0.52)	11.45	<0.001	2.43	Large
Observation Skills	1.98(0.65)	3.87(0.48)	14.67	<0.001	3.21	Very Large
Feedback Delivery	2.34(0.71)	4.12(0.46)	12.98	<0.001	2.87	Large
Professional Development Facilitation	2.12(0.69)	4.18(0.51)	13.76	<0.001	3.25	Very Large

Dimensions of Supervision	Pre-test M(SD)	Post-test M(SD)	t-value	p-value	Cohen's d	Interpretations by Lakens (2013)
Reflective Practice Support	2.15(0.72)	3.95(0.53)	12.34	<0.001	2.78	Large
Total Collegial Supervision	2.23(0.71)	4.05(0.51)	14.89	<0.001	2.98	Large

All five supervision dimensions showed substantial pre-post improvements, with effect sizes ranging from 2.43 to 3.25. Based on the effect size interpretation criteria described in the Methods section following Lakens (2013), the largest improvements were observed in Professional Development Facilitation ($d = 3.25$) and Observation Skills ($d = 3.21$). These findings suggest particularly strong gains in participants' competencies related to facilitating professional development and conducting classroom observations following participation in the program. Table 4 presents classroom observation findings from PAUD Annur Faridatul Irsyad, which was selected as an illustrative case to examine the implementation of deep learning practices following participation in the professional development program. These findings are presented as a case example and should not be interpreted as representative of all participating institutions.

Table 4. Observation Results of Deep Learning Implementation - Case Study of PAUD Annur Faridatul Irsyad

Deep Learning Indicator	Pre-test Skor	Post-test Skor	Improvement	Description Transformation
Inquiry-based Activities	2	5	+3	From teacher-centered explanations to child-led investigations
Higher-order Questioning	2	4	+2	From factual recall to open-ended analytical questions
Student Engagement	3	5	+2	From passive listening to active exploration
Metacognitive Strategies	1	4	+3	From no reflection to explicit thinking
Technology Integration	1	4	+3	From no technology to meaningful integration of digital tools
Authentic Assessment	2	4	+2	From quiz-based to portfolio documentation
Total Implementation	11/30	26/30	+15	Transformation from "Poor" to "Good"
Average Score	1.83	4.33	+2.50	136% improvement

The PAUD Annur Faridatul Irsyad case provides an illustrative example of how deep learning practices were implemented following participation in the program. While the case offers valuable insights into classroom-level changes, the findings should be interpreted as institution-specific rather than representative of all participating ECE institutions. Across six deep learning indicators, every measure improved, with total scores increasing from 11/30 to 26/30, representing an average gain of 2.50 points and a 136% improvement in implementation quality. These results indicate a marked enhancement in the implementation of deep learning practices following the intervention. Table 5 presents the results of the initial retention analysis conducted after the intensive offline sessions to assess participants' retention of the competencies developed during the program.

Table 5. Initial Retention Analysis of the Program (Intensive Offline Session Evaluation)

Sustainability Aspects	Retention Rate	Number	Percentage
Implementation of Deep Learning by Teachers	High	17/20	85%
	Medium	3/20	15%
	Low	0/20	0%
Collegial Supervision by Principal	High	16/20	80%
	Medium	4/20	20%
	Low	0/20	0%
Technology Integration in Learning	High	15/20	75%
	Medium	4/20	20%
	Low	1/20	5%
TPACK Competency	Fixed High	17/20	85%
	Decreased Slightly	3/20	15%
	Decreased Much	0/20	0%

A follow-up evaluation conducted during the Intensive Offline Session (July 10, 2025), approximately three weeks after the initial online training, assessed the continued implementation of four domains: deep learning practices, collegial supervision, technology integration, and TPACK-related competencies. Retention levels were categorized as high, medium, or low based on evidence gathered through follow-up observations, participant reflections, and implementation documentation. Across these domains, the follow-up evaluation indicated consistently high levels of maintenance, with an average score of 81% across the assessed indicators. Although this figure should not be interpreted as a participant-level retention rate, it suggests that the improvements observed during the program were largely maintained during the short-term follow-up period.

Qualitative Analysis: Key Transformations

Theme 1: Paradigm Shift from Surface to Deep Learning

Participants described changes in how they understood the concept of deep learning following the professional development program. Several teachers reported that, before the training, they associated effective teaching primarily with dedication, care, and positive relationships with children. Through the training activities, they began to view deep learning as a pedagogical approach that also emphasizes critical thinking, inquiry, reflection, and meaningful knowledge construction. As one teacher explained:

"I always thought that teaching with care and sincerity was already enough. After the training, I realized that deep learning also involves helping children think, ask questions, and explore ideas more deeply." (Teacher participant, translated from Bahasa Indonesia)

While participants generally expressed positive responses to this conceptual shift, the experiences reported varied across individuals. For some teachers, the transition involved rethinking long-established classroom routines, whereas others described it as an extension of practices they had already begun to develop. Overall, the findings suggest that a clearer understanding of the pedagogical dimensions of deep learning may have supported participants' efforts to adopt more inquiry-oriented teaching practices.

Theme 2: Technology as an Enabler, not an End

Perhaps the most practically significant outcome was how teachers came to understand technology as a tool in the service of learning rather than as an end in itself. The TPACK framework gave them a language and a structure for asking different questions. Nani (pseudonym), a principal who had led her school for more than five years, captured this well in her interview: teachers in her school had stopped asking "what tool can I use?" and started asking "what do I want children to understand deeply, and how can technology help get them there?" That reorientation, from technology-first to pedagogy-first thinking, is the kind of mindset shift that tends to stick. These reflections suggest that participants increasingly viewed technology as a pedagogical resource rather than the primary focus of instruction.

Theme 3: From Evaluative to Developmental Supervision

Participants' reflections suggested changes in how principals understood and enacted their supervisory roles following the program. Moving from evaluative to developmental supervision required some principals to reconsider traditional assumptions about leadership and instructional oversight. Several participants described a shift from emphasizing compliance and monitoring toward supporting teacher learning and professional growth. As Hanna (pseudonym), a principal with more than ten years of experience, reflected:

"I used to feel responsible for making sure everything went according to plan."

She explained that her perspective changed as she came to recognize that meaningful learning often involves exploration, experimentation, and opportunities for reflection. This realization influenced how she approached supervision, placing greater emphasis on supporting teachers' professional learning rather than primarily monitoring performance. Overall, these reflections suggest a shift in some principals' understanding of supervision as a process that can facilitate professional growth and collaborative learning.

Theme 4: Transforming Student Learning Experiences

The classroom observations provided examples of how participants adapted deep learning principles within their teaching practice. In one participating ECE institution, a lesson on plants that had previously focused on teacher explanation and worksheet completion was redesigned as an inquiry-based learning experience. As described by Lucy (pseudonym), a teacher with more than five years of ECE experience, children were encouraged to observe different plants, formulate questions, propose explanations, and conduct simple investigations. Reflecting on the activity, Lucy reported that the children generated questions beyond those anticipated in the lesson plan and participated actively throughout the inquiry process. These observations suggest a shift toward more inquiry-oriented learning practices and greater opportunities for active student participation.

Theme 5: Integration of Creative Technologies in a Resource-Limited Context

Participants reported increased confidence in making pedagogically informed decisions regarding the use of digital technologies in classroom practice. Rather than emphasizing technology use for its own sake, teachers described selecting digital tools that aligned with their instructional objectives and classroom needs. Several examples emerged during interviews and observations, including the use of WhatsApp for communication and learning documentation, Canva for the development of visual learning materials, and digital portfolios for documenting children's learning progress. As Windy (pseudonym) explained, digital tools provided additional opportunities to support classroom activities and document learning processes. These reflections suggest that participants increasingly viewed technology as a means of supporting instructional goals rather than as an end in itself.

Theme 6: Sustainability and Continuous Learning

An additional finding was the emergence of collaborative interactions among participants following the formal training activities. WhatsApp groups that were initially established for program coordination became spaces where participants exchanged teaching ideas, discussed implementation challenges, and shared classroom experiences. As Puspita (pseudonym) noted:

"We no longer feel isolated in trying new approaches. There is a sense of collective responsibility to continuously improve our practice."

Participants also described adapting deep learning principles to their local educational and cultural contexts while maintaining alignment with the goals of the professional development program. Although the study did not examine the long-term sustainability of these interactions, the follow-up data suggest that collaborative communication and peer support continued during the short-term post-program period.

Discussion

The findings of this study demonstrated statistically significant improvements in teachers' TPACK competencies and principals' collegial supervision competencies following the intervention. In addition, descriptive findings from classroom observations indicated improvements in the implementation of deep learning practices, while follow-up evaluation suggested that most participants maintained the competencies developed during the program. Collectively, these findings indicate that the integrated professional learning model was associated with improvements in teachers' pedagogical and technological competencies, enhanced principals' instructional leadership practices, and supported ongoing professional learning within rural early childhood education settings. Beyond these quantitative and descriptive findings, evidence from classroom observations, interviews, and participant reflections revealed meaningful changes in pedagogical beliefs, supervisory practices, and collaborative professional culture. These findings are broadly consistent with previous studies suggesting that integrated professional development can support instructional competence, leadership capacity, and sustainable educational improvement (Çam & Koç, 2024; Darmawan et al., 2025; He et al., 2024).

The substantial gains observed in Technology Knowledge and Technological Pedagogical Knowledge suggest that participants strengthened their capacity to integrate technology into instructional practice. Interview data indicated that teachers increasingly described selecting digital tools based on pedagogical considerations rather than availability alone, while classroom

observations provided examples of more purposeful technology use during learning activities. These findings are consistent with previous studies that have highlighted the importance of aligning technology use with pedagogical objectives in teacher professional development (Jiménez-Sierra et al., 2023; Çam & Koç 2024). In the present study, participants also reported that mentoring activities, collegial supervision, and opportunities for reflection supported their learning throughout the program. However, the study was not designed to determine the relative contribution of specific program components. Therefore, the findings should be interpreted as suggesting a possible role for collaborative learning and reflective practice rather than demonstrating a specific mechanism of change.

A similarly substantial improvement was observed in principals' collegial supervision competencies, particularly in professional development facilitation and classroom observation. Participant reflections indicated a shift in how principals perceived supervision, moving from a compliance-oriented activity toward a process that supports teacher learning and professional growth. These findings are broadly consistent with previous studies highlighting the importance of instructional leadership in fostering teacher development (He et al., 2024; Khotimah et al., 2025; Wiyono et al., 2021). Participants frequently referred to coaching activities, collaborative dialogue, and classroom observation as valuable learning experiences throughout the program. However, the study was not designed to determine the relative contribution of prior leadership experience and program participation to the observed changes. Therefore, these findings should be interpreted as indicating potential factors associated with participants' reported professional growth rather than as evidence of specific causal mechanisms.

The observed improvements in deep learning implementation further demonstrate that the intervention successfully translated professional learning into authentic classroom practice. Classroom observations showed that teachers increasingly designed inquiry-oriented learning experiences that encouraged children to investigate, question, and construct understanding, while interview data revealed corresponding shifts in teachers' instructional beliefs. These findings are consistent with research highlighting inquiry-based pedagogy and active learning as key mechanisms for meaningful learning (Attard et al., 2021; Huang et al., 2025; Parker et al., 2022; Pasek et al., 2020). However, unlike previous studies that primarily examined instructional innovations independently, the present findings suggest that sustained mentoring, reflective supervision, and iterative lesson refinement created a coherent learning process that enabled teachers to transfer professional knowledge into everyday classroom practice more effectively.

The retention findings provide further evidence that the observed improvements extended beyond immediate training outcomes into participants' professional practice. Follow-up evaluation approximately three weeks after the intervention demonstrated that most participants maintained the competencies developed during the program, while qualitative evidence indicated that collaborative professional learning continued through peer interaction, reflective discussion, and ongoing classroom implementation. Although considerable Lewis et al. (2015) variation was reported in the sustainability of professional development outcomes, the consistently high retention observed in this study suggests that school-embedded mentoring and collaborative reflection reinforced newly acquired competencies through continuous application rather than one-off training activities. However, technology integration showed slightly lower retention compared with other competency areas. While the present study did not specifically investigate the factors contributing to this difference, the finding suggests the need for further research to examine contextual and institutional conditions that may influence the long-term sustainability of technology-supported pedagogical practices.

Taken together, the findings suggest that participation in a professional development program combining TPACK-oriented instruction, collegial supervision, mentoring, and collaborative reflection was associated with improvements in teachers' and principals' reported competencies and practices. Because the study evaluated the intervention as an integrated program, it was not possible to determine the relative contribution of individual components to the observed changes. Nevertheless, the findings indicate that participants perceived value in the combination of professional learning activities implemented throughout the program.

These findings may offer useful insights for educators, school leaders, and local education stakeholders seeking to strengthen professional learning opportunities in rural early childhood

education settings. In contexts where access to professional development is limited, approaches that incorporate mentoring, collaborative learning, reflective practice, and technology integration may warrant further exploration. Future research should examine the scalability, long-term sustainability, and effectiveness of similar professional development approaches across diverse educational settings, including their potential influence on children's learning and developmental outcomes.

LIMITATION

Several limitations should be considered when interpreting the findings. First, the study employed a one-group pretest-posttest design without a control group, limiting the ability to attribute observed changes solely to the intervention. Second, the relatively small sample size and purposive participant selection may limit the transferability of the findings to other contexts. Third, repeated measurement and self-report instruments may have introduced response bias, including social desirability effects. Fourth, classroom observation data on deep learning implementation were drawn from a single illustrative institution and therefore should not be interpreted as representative of all participating ECE institutions. In addition, the study did not assess child learning or developmental outcomes directly, making it difficult to determine how observed changes in teacher and principal practices translated into student-level outcomes. Finally, the three-week follow-up period was relatively short and does not permit conclusions regarding the long-term sustainability of the reported changes.

CONCLUSION

This study examined the implementation of a professional development program that combined TPACK-oriented instruction, collegial supervision, mentoring, and collaborative reflection in rural early childhood education settings in Karangpawitan District, Indonesia. The findings indicated significant pre-post improvements in teachers' TPACK competencies and principals' collegial supervision competencies following participation in the program. Qualitative findings further suggested changes in participants' perspectives regarding technology integration, instructional practice, and developmental approaches to supervision. Given the one-group pretest-posttest design and short follow-up period, the findings should be interpreted as evidence of positive changes observed following participation in the program rather than as proof of long-term effectiveness or causal impact. Nevertheless, the study provides preliminary evidence that integrated professional learning approaches may support teacher and principal development in resource-constrained educational contexts. From a practical perspective, the findings highlight the potential value of combining technology integration, collaborative supervision, mentoring, and reflective practice within professional development initiatives. Rather than extending the TPACK framework theoretically, this study illustrates its application within a rural Indonesian ECE context. Future research involving larger samples, comparison groups, longer follow-up periods, and direct measures of child outcomes is needed to strengthen the evidence base and examine the broader applicability of these findings.

ETHICS AND CONSENT

The authors declare no conflict of interest regarding the publication of this article and affirm that the data and content are free from plagiarism. The program was conducted under formal authorization from the Garut Regency Education Office, documented through an official assignment letter, with consent obtained from the participating school leadership and teachers. All data were handled confidentially and used solely for academic and reporting purposes, and photographs were taken and used with institutional and participant permission. The authors clarify that the activities did not involve children as research participants and did not involve classroom observations, child-related artifacts, or personally identifiable information concerning children; therefore, child consent or assent was not required. The authors thank the school leadership and teachers of PAUD Annur Faridatul Irsyad for their participation. This community service program was conducted

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AUTHOR CONTRIBUTIONS

SS contributed to the conceptualization, research design, methodology, coordination of the participatory action research, and development of the professional development program. YR contributed to the conceptualization, supervision, validation of the research instruments, and interpretation of the findings. TC contributed to the methodology, development and validation of the quantitative instruments, and data collection. NS contributed to the research implementation, participant coordination, data collection, and qualitative data analysis. HD contributed to the development of the early childhood education learning framework, classroom observations, and interpretation of deep learning practices. SN contributed to data curation, documentation of the intervention process, qualitative data collection, and analysis of participant reflections. AD contributed to statistical analysis, pre-post comparison, effect-size calculation, and presentation of the quantitative results. PA contributed to data validation, synthesis of quantitative and qualitative findings. SS and YR supervised the overall research process and critically revised the manuscript.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the authors used generative AI and AI-assisted technologies solely to support language editing, grammar checking, and improvement of clarity and readability. AI tools were not used to generate, analyze, or interpret the research data or to determine the study's findings and conclusions. All research procedures, data analysis, interpretation of results, and substantive academic decisions were conducted and verified by the authors. The authors critically reviewed and revised all AI-assisted content and take full responsibility for the accuracy, originality, and integrity of the final manuscript.

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