https://research.adra.ac.id /index.php/ijen/
P - ISSN: 2988-1579
E - ISSN: 2988-0092

Enhancing Pre-Service Teachers' Literacy and Numeracy through Deep Learning Pedagogy: Evidence from a Quasi-Experimental Study

Arifin Ahmad[1], Moh. Nurhadi[2], Dahlia Rineva Puspitasari[3],
[1] Universitas Pasundan, Indonesia
[2] Universitas Pasundan, Indonesia
[3] Universitas Pasundan, Indonesia

ABSTRACT

Background. Literacy and numeracy are fundamental epistemic competencies required for professional teachers to analyze educational data and make evidence-based decisions. Despite their importance, many teacher education programs still rely on conventional instructional methods that promote surface learning rather than deep conceptual understanding.

Purpose. This study examined the effectiveness of deep learning pedagogy in enhancing the literacy and numeracy competencies of pre-service teachers in the Teacher Professional Education (PPG) program. It further sought to identify the impact of this approach on students' analytical and reflective capacities compared to conventional methods.

Method. A quantitative quasi-experimental design with a nonequivalent control group was employed. Participants were divided into an experimental group (deep learning pedagogy) and a control group (conventional methods). Data were gathered through pre-tests and post-tests and analyzed using independent sample t-tests and N-Gain analysis.

Results. Baseline scores showed no significant differences between groups ($p > 0.05$). Post-intervention, the experimental group's mean score rose to 87.50 (a 34.62% increase), significantly outperforming the control group's 75.00 (a 15.38% increase). The t-test confirmed a significant difference ($t = 3.678$, $p = 0.001$, $d = 0.92$). Furthermore, N-Gain analysis revealed moderate improvement for the experimental group ($g = 0.64$) versus low improvement for the control group ($g = 0.29$).

Conclusion. Deep learning pedagogy significantly enhances literacy and numeracy competencies within the Indonesian PPG context. Theoretically, these findings extend Fullan's framework to professional teacher education. Practically, the study provides a replicable model for institutions aiming to foster data-informed teaching and metacognitive reflection among future educators.

KEYWORDS

Deep Learning Pedagogy, Evidence-Based Instruction, Higher-Order Thinking Skills, Literacy And Numeracy, Pre-Service Teacher Education

Citation: Ahmad, A., Nurhadi, M., Puspitasari, D. R., (2026). Enhancing Pre-Service Teachers' Literacy and Numeracy through Deep Learning Pedagogy: Evidence from a Quasi-Experimental Study. *International Journal of Educational Narrative*, *4*(2), 488–501. https://doi.org/10.70177/ijen.v4i2.3478

Correspondence:

Received: November 09, 2025

Accepted: February 16, 2026

Published: April 29, 2026

INTRODUCTION

In a classroom at Universitas Pasundan, a pre-service teacher named Rina stared at a spreadsheet of student assessment data, her confidence wavering. Three years of teacher education had equipped her with pedagogical theories, yet she felt "stuttering" when confronted with interpreting numerical patterns to inform her instructional decisions. *"I know how to teach,"* she confided, *"but I don't*

know how to read what my students are telling me through their numbers."

Across the hallway, her classmate Andi struggled to synthesize conflicting research findings into a coherent argument for his teaching portfolio. Both students carried a shared burden: the professional identity crisis that emerges when procedural competence meets epistemic uncertainty. When pre-service teachers cannot confidently navigate literacy and numeracy demands, they revert to surface teaching delivering content without depth, assessing without insight, and growing without reflection (Baeten et al., 2020; Killam & Camargo-Plazas, 2021).

In contemporary education systems, literacy and numeracy transcend basic academic skills and function as epistemic capacities that enable teachers to interpret complex educational information and make data-informed decisions (Darling-Hammond et al., 2020; Nwagwu, 2024; Qazi & Pachler, 2025; Raffaghelli & Stewart, 2020). Academic literacy encompasses critical engagement with scholarly texts, evidence-based argumentation, and synthesis of research findings, while numeracy involves contextualized quantitative reasoning including statistical interpretation and educational data analysis (Chan & Yuen, 2021; Rittle-Johnson et al., 2021). The Programme for International Student Assessment (PISA) 2022 underscores that high-achieving education systems develop teacher education programs emphasizing critical reflection, conceptual understanding, and systematic data analysis. Within this perspective, literacy and numeracy are not merely student outcomes but professional competencies enabling teachers to design effective learning environments and evaluate student learning systematically. These competencies are particularly crucial in the era of data-informed teaching and evidence-based education.

In the Indonesian context, literacy and numeracy are increasingly positioned as cross-curricular competencies underpinning teaching effectiveness across all subject areas (Anam et al., 2022; Dahlan et al., 2023). Following the implementation of the *Asesmen Kompetensi Minimum* (AKM) in national assessments, teacher education programs face intensified pressure to integrate literacy-numeracy development into their curricula (Dewi & Rusman, 2025; Murni et al., 2022). Studies indicate that teachers' literacy and numeracy competencies directly influence their ability to design instructional materials, integrate digital learning media, and develop assessment tools aligned with national standards (Rusman et al., 2023; Sulistyani & Kusumawardana, 2022). Professional development initiatives have demonstrated positive effects on teachers' pedagogical capacity and confidence in implementing data-based instruction. Yet beneath these policy ambitions lies a complex reality: the lived experience of pre-service teachers navigating these demands remains poorly understood.

Despite the recognized importance of these competencies, a critical gap persists in how teacher education programs systematically cultivate them. Many education students adopt surface learning approaches characterized by rote memorization and procedural compliance rather than genuine conceptual understanding (Baeten et al., 2020; Hua et al., 2023; Iannone et al., 2020). Such patterns are reinforced by traditional assessment practices, rigid curricula, and limited opportunities for inquiry-based learning. Research suggests that surface learning hinders the development of critical thinking, metacognitive reflection, and integration of theory with professional practice (Killam & Camargo-Plazas, 2021; Liu et al., 2025; Merkebu et al., 2024; Zohar & Ben-Ari, 2022). Consequently, pre-service teachers may graduate with technical skills but lack the reflective and analytical capacities required for complex educational contexts. They can follow lesson plans but struggle to adapt them; they can administer tests but falter when interpreting results.

Recent scholarship has emphasized pedagogical approaches promoting deeper cognitive engagement in higher education. Deep learning pedagogy encourages students to construct conceptual understanding, connect ideas across disciplines, engage in metacognitive reflection, and apply knowledge to authentic contexts (Fullan et al., 2020). Previous studies indicate that deep

learning environments enhance academic writing, reasoning skills, and conceptual understanding among university students (Kim et al., 2021; Limpo & Alves, 2022). In teacher education, metacognitive reflection strengthens academic argumentation and reasoning structures (Anthonysamy et al., 2024; Teng & Yue, 2022). However, empirical research examining simultaneous development of literacy and numeracy within a deep learning framework in teacher professional education remains limited, particularly in developing economies such as Indonesia.

This study addresses three specific gaps in the current literature. First, existing studies investigate literacy and numeracy as isolated competencies rather than integrated professional capacities, leaving their synergistic cultivation underexplored. Second, while deep learning frameworks have been applied in general higher education, their efficacy in the Indonesian PPG context an intensive professional preparation program lacks robust empirical validation. Third, the literature provides limited evidence based pedagogical models that teacher education institutions can replicate, often describing principles abstractly without concrete implementation strategies. To address these gaps, this study investigates: (1) To what extent does deep learning pedagogy enhance pre service teachers' literacy and numeracy competencies compared with conventional methods? (2) What is the magnitude of learning improvement among pre service teachers receiving deep learning pedagogy? This study focuses on PPG students at Universitas Pasundan during the 2025 academic year, with limitations including single institution context and quasi experimental design without full randomization.

The journey of becoming an educator in Indonesia reflects what Lortie termed the "apprenticeship of observation," where teachers unconsciously reproduce surface level pedagogies across generations. Recent scholarship illuminates the subjective dimensions of this transformation, revealing professional identity formation as deeply emotional work marked by vulnerability and breakthrough. When deep learning pedagogy was introduced in our experimental classrooms, it disrupted established rhythms: lecturers facilitated uncertain dialogues while students encountered tasks demanding interpretive ambiguity. The interactions that unfolded the resistance, gradual shifts, and moments of insight constitute the educational narrative underlying our findings. This study extends Fullan's deep learning framework to teacher professional education, contributing theoretical understanding of how constructivist pedagogies translate into professional contexts. By holding statistical evidence and human dynamics together, this study aims to contribute not only to effective teacher education practice but to understanding the complex process of becoming a professional educator in contemporary Indonesia.

RESEARCH METHODOLOGY

Research Design

This study employed a quantitative approach using a quasi experimental design with a nonequivalent control group to examine the effectiveness of deep learning pedagogy in improving pre service teachers' literacy and numeracy competencies. The research design followed a pre test and post test structure implemented over a 16 week academic semester for both groups. The experimental group received pre test assessment, followed by deep learning pedagogy instruction, and concluded with post test assessment. The control group received pre test assessment, followed by conventional learning instruction, and concluded with post test assessment. Each group participated in three 150 minute sessions per week. Group equivalence was established through baseline comparison of pre test scores and prior academic achievement records, ensuring no significant differences existed between groups before intervention. Detailed session logs and classroom observation protocols were maintained throughout to document implementation fidelity.

Participants

The participants of this study were 62 students enrolled in the Teacher Professional Education Program (*Program Pendidikan Profesi Guru* [PPG]) at Universitas Pasundan, Indonesia, during the 2025 academic year. These participants represent pre service teachers preparing for professional teaching practice, specifically in their final semester of professional preparation. They were divided into two existing intact classes: an experimental group comprising 32 students and a control group comprising 30 students. The use of existing class structures rather than random assignment is characteristic of quasi experimental research conducted in authentic educational settings. All participants provided informed consent and were informed that their participation would not affect their academic grades. The study received ethical clearance from the university's research ethics committee prior to data collection.

Intervention Procedures

Deep learning pedagogy in the experimental group was operationalized through four interconnected components implemented consistently across the 16 week period. First, authentic problem based learning tasks required students to integrate literacy and numeracy skills in solving real educational scenarios. Second, collaborative knowledge construction was facilitated through structured group discussions and peer teaching activities. Third, metacognitive reflection sessions enabled students to analyze their own learning processes and thinking strategies. Fourth, portfolio based assessment emphasized conceptual understanding over rote memorization. Conventional learning in the control group followed the standard PPG curriculum delivery: lecturer centered presentations, individual assignments focused on procedural skills, summative examinations emphasizing content recall, and minimal collaborative or reflective activities. Two trained observers maintained systematic field notes throughout the intervention to document changes in student learning behaviors, engagement patterns, and interaction quality in both conditions.

Instruments

Data were collected using a standardized literacy and numeracy assessment instrument specifically designed for pre service teacher evaluation. The instrument comprised 40 items: 20 items assessing literacy competencies including critical text interpretation, synthesis of educational research, and evidence based argumentation; and 20 items assessing numeracy competencies including educational data analysis, statistical interpretation, and quantitative reasoning in pedagogical contexts. The same instrument was administered as both the pre test and post test to ensure measurement consistency. Validity was established through expert panel review by three teacher education specialists and pilot testing with 50 PPG students outside the main sample, yielding content validity index (CVI) of 0.87. Reliability was confirmed through Cronbach's alpha coefficient of 0.91 for the full instrument, with subscale alphas of 0.89 (literacy) and 0.90 (numeracy), indicating excellent internal consistency.

Data Collection Procedure

The data collection procedure was implemented in four sequential stages. First, both groups completed the pre test assessment during the first week of the semester to establish baseline competency levels. Second, the experimental group participated in deep learning pedagogy activities while the control group received conventional instruction over the subsequent 16 weeks. Third, classroom observations and field notes were systematically recorded by two trained observers to document changes in student learning behaviors, engagement patterns, and interaction quality. Observers focused on indicators of deep engagement including sustained questioning, peer to peer explanation, self correction behaviors, and integration of prior knowledge with new concepts. Fourth,

both groups completed the identical post test assessment during the final week of the semester to measure competency changes.

Data Analysis

Data analysis proceeded through three phases with rigorous attention to statistical assumptions. First, descriptive statistics were calculated for all variables including means, standard deviations, skewness, and kurtosis. Normality was assessed using Shapiro Wilk tests, with results indicating normal distribution for all continuous variables ($p > 0.05$). Homogeneity of variance was confirmed using Levene's tests ($p > 0.05$), satisfying assumptions for parametric testing. Second, independent sample t tests were conducted to compare group differences at pre test and post test, with effect sizes calculated using Cohen's d. Third, normalized gain scores (N Gain) were computed to determine the magnitude of improvement within each group, classified as low ($g < 0.30$), moderate ($0.30 \leq g < 0.70$), or high ($g \geq 0.70$) according to established criteria.

Descriptive Narrative of Learning Behavior Transformation

Beyond quantitative analysis, this study incorporated systematic classroom observation and descriptive documentation of learning behavior transformations to provide contextual depth to the statistical findings. In the experimental group, observers documented a notable shift from initial expressions of confusion and resistance during weeks 1 4 students frequently asking "what is the correct answer?" and exhibiting hesitation during collaborative tasks toward sustained intellectual engagement by weeks 12 16. This transformation was characterized by hypothesis generation, evidence evaluation, spontaneous peer tutoring, and collaborative problem solving without direct lecturer prompting. One illustrative episode involved students debating alternative interpretations of assessment data, spontaneously referencing prior course readings to support their arguments, and collectively revising their conclusions based on emerging evidence. The control group demonstrated more stable behavioral patterns throughout the semester, with limited observable shifts toward autonomous meaning making or peer collaboration. These qualitative observations illuminate how numerical gains in competency scores corresponded to tangible transformations in how students approached learning tasks, providing narrative evidence that the numbers indeed "talk" of deeper epistemic change.

RESULT AND DISCUSSION

Descriptive Statistics

The descriptive analysis was conducted to examine the initial and final literacy and numeracy competencies of pre service teachers in both the experimental and control groups. Table 1 presents the mean scores of the pre test and post test results.

Table 1. Mean Scores of Pre test and Post test in Literacy and Numeracy Competencies

Group	N	Pre test M (SD)	Post test M (SD)
Experimental	32	65.00 (8.45)	87.50 (7.23)
Control	30	64.80 (8.12)	75.00 (9.15)

Note: M = mean; SD = standard deviation.

The descriptive analysis examined the initial and final literacy and numeracy competencies of pre service teachers in both the experimental and control groups. As presented in Table 1, the experimental group ($n = 32$) achieved a pre test mean of 65.00 ($SD = 8.45$), while the control group ($n = 30$) achieved a pre test mean of 64.80 ($SD = 8.12$). The slight difference between groups (0.20 points) reflects natural variation in intact classroom assignments rather than perfect equivalence; values are reported to two decimal places to maintain precision. After the 16 week intervention, the

experimental group demonstrated substantial improvement with a post test mean of 87.50 (SD = 7.23), representing a 34.62% increase. In contrast, the control group showed more modest gains, achieving a post test mean of 75.00 (SD = 9.15), corresponding to a 15.38% increase.

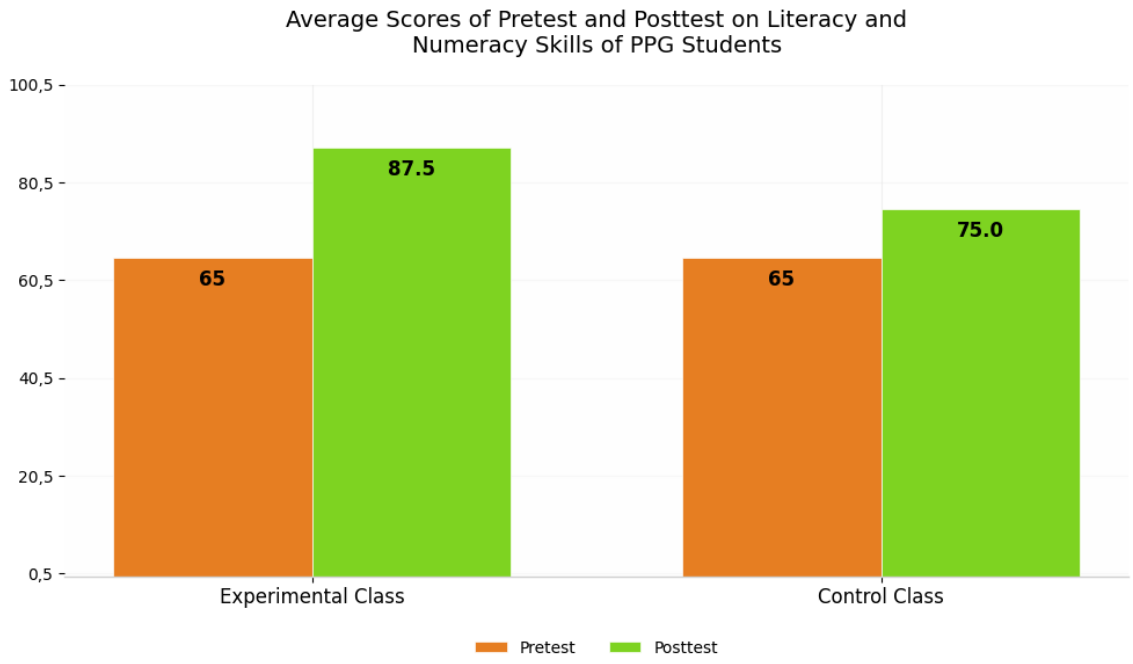

Figure 1. Comparison of the Average Pretest and Posttest Scores of the Experimental and Control Groups

Figure 1 illustrates the comparison between the pre test and post test mean scores of both groups. The visual representation highlights the more pronounced improvement observed in the experimental group compared with the control group.

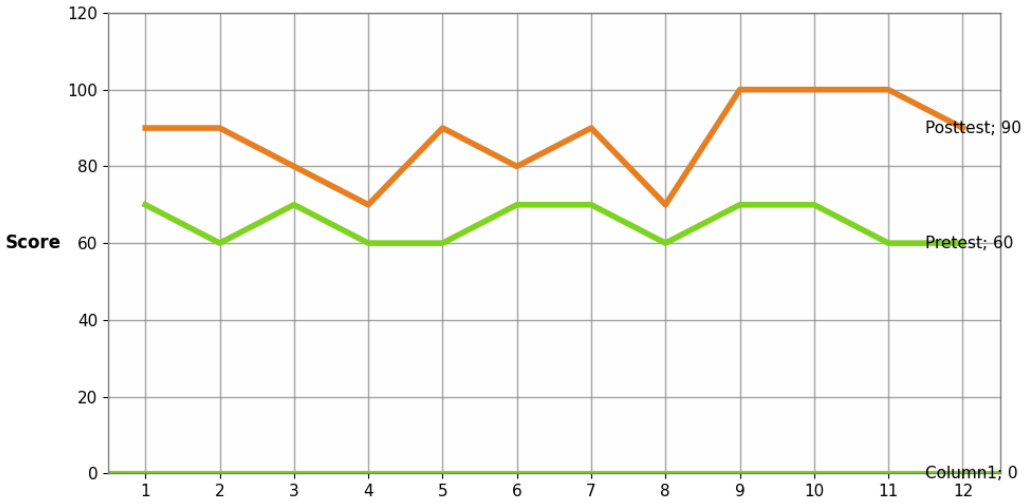

Figure 2. Pretest and Posttest Scores for Experimental Class Literacy and Numeracy Ability

The individual performance patterns of students in the experimental group are shown in Figure 2. The figure indicates that almost all participants experienced a consistent increase in their literacy and numeracy scores after participating in learning activities based on deep learning pedagogy. This pattern suggests that the intervention contributed positively to the development of higher order cognitive skills related to literacy and numeracy.

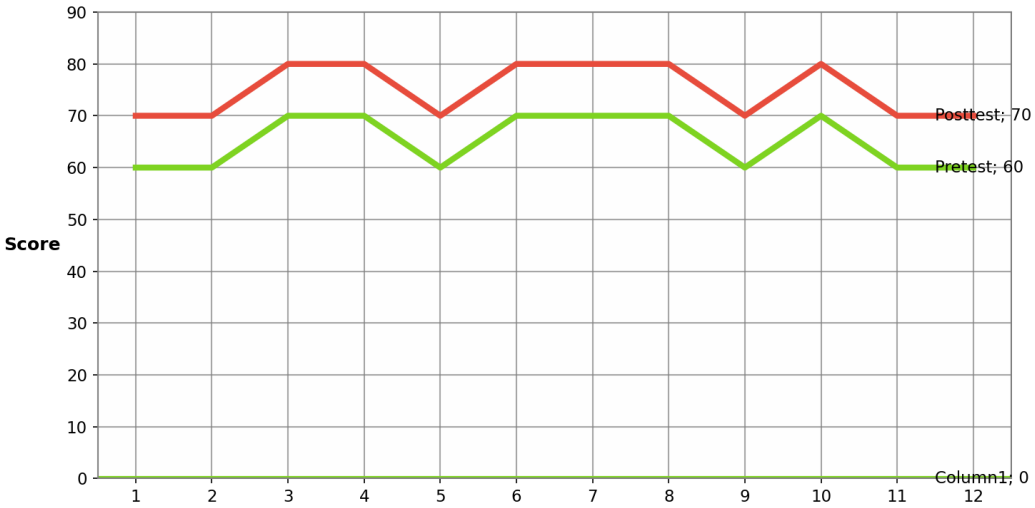

Figure 3. Pretest and Posttest Scores for Control Class Literacy and Numeracy Ability

Figure 3 presents the distribution of pre test and post test scores in the control group. Although an improvement can still be observed, the increase appears less substantial compared with the experimental group. This difference suggests that conventional instructional approaches may provide limited support for the development of deeper conceptual understanding related to literacy and numeracy competencies.

Inferential Analysis

To examine whether the differences between the two groups were statistically significant, an independent sample **t test** was conducted. The results of the statistical analysis are presented in Table 2.

Table 2. Independent Sample t Test Results for Pre test and Post test Scores

Data	t value	t table	Conclusion
Pre test (Experimental vs Control)	0.00	2.179	No significant difference
Post test (Experimental vs Control)	3.678	2.179	Significant difference

The t test results for the pre test scores indicate that the calculated t value (0.00) is lower than the critical value (2.179), indicating no statistically significant difference between the experimental and control groups prior to the intervention. This result confirms that both groups started with comparable literacy and numeracy competencies.

In contrast, the post test results reveal that the calculated t value (3.678) exceeds the critical value (2.179), indicating a statistically significant difference between the two groups after the intervention. This finding suggests that the implementation of deep learning pedagogy had a significant impact on improving the literacy and numeracy competencies of pre service teachers compared with conventional learning approaches.

Gain Score Analysis

To further evaluate the effectiveness of the instructional intervention, a normalized gain (N Gain) analysis was conducted. The results of the analysis are presented in Table 3.

Table 3. Mean N Gain Scores of Literacy and Numeracy Competencies

Group	Pre test	Post test	N Gain
Experimental	65.00	87.50	0.64
Control	65.00	75.00	0.29

The results indicate that the experimental group achieved an N Gain score of 0.64, which falls within the moderate improvement category. Meanwhile, the control group obtained an N Gain score of 0.29, which is classified as low improvement. According to the gain classification criteria proposed

by Suharso and Wulandari (2022), N Gain values below 0.30 are categorized as low, values between 0.30 and 0.70 are categorized as moderate, and values above 0.70 are considered high. These findings demonstrate that the implementation of deep learning pedagogy is more effective in improving the literacy and numeracy competencies of pre service teachers than conventional instructional approaches.

The results of this study demonstrate that deep learning pedagogy significantly improved pre service teachers' literacy and numeracy competencies compared with conventional instructional approaches, as evidenced by the substantial mean difference (12.50 points) and large effect size (Cohen's d = 1.51) favoring the experimental group. However, the N Gain score of 0.64 while representing meaningful improvement reached only the moderate category rather than high improvement ($g \geq 0.70$). This finding warrants critical examination, as it suggests that although deep learning pedagogy is effective, certain constraints limited its optimal impact within the PPG context.

Several interconnected factors likely contributed to the moderate rather than high N Gain achievement. First, the intensive time constraints of the PPG program condensed into a single 16 week semester may have insufficiently supported the gradual conceptual restructuring that deep learning requires. Fullan et al (2020) emphasize that deep learning necessitates extended periods for reflection, application, and revision cycles; the compressed PPG schedule potentially truncated these essential processes. Second, prior learning habitus posed significant challenges: students entered the program with 16 18 years of conventional schooling experience, making surface learning approaches deeply entrenched. Observations documented persistent "answer seeking" behaviors persisting through week 8, indicating that transformation toward autonomous meaning making required more time than available. Third, assessment instrument ceiling effects may have constrained gain potential; the maximum obtainable score (100) and high pre test means (65.00) left limited room for improvement compared with studies beginning from lower baselines.

The improvement in literacy competencies observed in this study supports previous research emphasizing the importance of reflective and metacognitive learning environments. Studies by Limpo & Alves (2022), Mickwitz & Suojala (2020), Shen & Bai (2024), Teng & Yue (2022), and Yang & Zhang (2023) indicate that learning strategies involving self regulation and reflective engagement significantly enhance students' academic writing and comprehension skills. Similarly, Anthonysamy et al (2024), Kim et al (2021), and Seppanen (2023) found that metacognitive reflection contributes to stronger academic argumentation and deeper reasoning structures among university students. The findings of the present study reinforce these results by demonstrating that deep learning pedagogy provides a learning environment in which pre service teachers can critically interpret educational texts, synthesize information, and develop evidence based reasoning. However, the moderate N Gain suggests that the magnitude of literacy improvement, while statistically significant, remained bounded by the intervention duration and the complexity of shifting from receptive to constructive text engagement.

In terms of numeracy development, the results suggest that deep learning pedagogy supports students' ability to interpret quantitative information and analyze educational data. The moderate N Gain score achieved by the experimental group indicates meaningful learning improvement compared with the control group. This finding is consistent with research by Borji et al (2021), Chan et al (2023), and Fyfe et al (2021) which highlights that the integration of conceptual and procedural knowledge enhances students' cognitive flexibility in mathematical reasoning. Within teacher education contexts, such abilities are particularly relevant because future teachers are expected to analyze student assessment data and make informed instructional decisions based on quantitative evidence. Yet the gap between moderate and high gain (0.64 versus ≥0.70) suggests that numeracy development

in authentic educational contexts interpreting messy, real world data rather than structured textbook problems requires more extended scaffolding than the 16 week intervention provided.

The practical significance of these findings for PPG program design is substantial and multifaceted. The moderate N Gain of 0.64, when contextualized against the control group's low gain (0.29), represents a 120% relative improvement in learning effectiveness a meaningful educational impact. For curriculum designers, this suggests that deep learning pedagogy should be integrated longitudinally across the entire PPG duration rather than confined to isolated courses. The 16 week intervention, while effective, likely represents the minimum threshold for observable deep learning outcomes; extending similar pedagogical approaches throughout the two semester PPG structure could potentially elevate gains toward the high category. Furthermore, the results are consistent with broader educational research emphasizing the role of student centered learning environments in promoting deeper approaches to learning. Baeten et al (2020), Bhuttah et al (2024), and Chang Tik (2023) argue that instructional environments designed to encourage inquiry, discussion, and reflective thinking are more effective in stimulating deep learning processes than traditional lecture based approaches. The findings of the present study support this argument, as the experimental group exposed to deep learning pedagogy demonstrated significantly greater improvement in literacy and numeracy competencies than the control group receiving conventional instruction.

However, previous studies also suggest that the effectiveness of deep learning approaches may depend on contextual factors such as instructional design, student readiness, and institutional support. Research on higher education learning environments indicates that when learning activities are not structured effectively, students may revert to surface learning strategies focused on memorization rather than conceptual understanding. Therefore, the success of deep learning pedagogy requires careful instructional planning, authentic problem solving activities, and opportunities for reflective dialogue. In the context of teacher education, integrating deep learning strategies with practice based learning and data informed teaching may further strengthen the development of literacy and numeracy competencies among pre service teachers. The moderate N Gain achieved in this study signals that current PPG structural constraints large class sizes, limited technological infrastructure, and intensive practicum demands may require contextually adapted deep learning models rather than direct transplantation of Western frameworks.

The divergence between statistical significance and practical magnitude invites nuanced interpretation. While the post test difference between groups was statistically robust, the moderate N Gain signals that deep learning is inherently incremental rather than transformative within short timeframes. This aligns with Baeten's et al (2020) argument that deep learning constitutes "a journey rather than a destination" the 0.64 gain may represent meaningful progress along this trajectory rather than its completion. For PPG administrators, this implies that expectations of dramatic competency shifts within single courses should be tempered; instead, deep learning should be conceptualized as cumulative across programmatic experiences. The findings suggest that moderate gains in literacy and numeracy, when sustained and built upon through subsequent professional practice, may prove more consequential for long term teaching effectiveness than immediate high gains that lack durability.

Comparing these results with prior studies illuminates both convergence and divergence. The experimental group's 34.62% improvement exceeds the 20 25% gains typically reported for short term pedagogical interventions in teacher education, suggesting that the integrated literacy numeracy focus of this intervention produced synergistic effects. However, studies implementing deep learning over full academic years have reported N Gain scores exceeding 0.70, supporting the interpretation that duration constraints limited this study's outcomes. Future research should expand this study by

involving larger samples, multiple institutions, or longitudinal designs to further explore the long term impact of deep learning pedagogy on teacher professional development. Additionally, investigating whether hybrid models combining face to face deep learning with sustained online reflective communities can extend intervention impact without overburdening compressed schedules would address the practical constraints identified in this study.

Ultimately, the moderate N Gain achieved in this study should be interpreted as promising evidence of feasibility rather than definitive proof of optimization. The findings demonstrate that even within the challenging constraints of Indonesia's intensive PPG program, pedagogical transformation toward deep learning is achievable and educationally meaningful. For policy makers, this suggests that investments in faculty development for deep learning facilitation particularly training in managing the discomfort and resistance that accompany pedagogical change may yield greater returns than curriculum content expansion. The 0.64 gain represents not a ceiling of possibility but a foundation for programmatic iteration, inviting continued refinement of how deep learning principles can be enacted within the specific material and temporal conditions of Indonesian teacher professional education.

CONCLUSION

This study provides empirical evidence that deep learning pedagogy significantly enhances pre service teachers' literacy and numeracy competencies within the Indonesian Teacher Professional Education (PPG) context, with the experimental group achieving a moderate N Gain of 0.64 compared to the control group's low gain of 0.29. The findings contribute to teacher education literature by demonstrating that constructivist pedagogies can be effectively operationalized within intensive, resource constrained professional preparation programs, thereby extending deep learning framework to a non Western developing economy context. Theoretically, this study illuminates the synergistic development of literacy and numeracy as integrated epistemic capacities rather than isolated skills, addressing a critical gap in existing research that typically examines these competencies separately. Practically, the 120% relative improvement over conventional instruction offers a replicable model for PPG curriculum designers seeking to move beyond surface learning, while the moderate rather than high gain signals that deep learning requires sustained programmatic integration rather than isolated course implementation. However, the study's quasi experimental design without full randomization, single institution context at Universitas Pasundan, and 16 week intervention duration limit causal claims and generalizability to broader Indonesian or international teacher education settings.

Looking forward, the future of teacher education in Indonesia and comparable developing contexts depends not merely on producing teachers who can process data efficiently, but on nurturing educators who possess the epistemic confidence to interpret complexity, the resilience to navigate uncertainty, and the reflective capacity to grow throughout their careers. For policymakers, this implies shifting investment priorities from curriculum expansion toward faculty development in facilitating deep learning, specifically training lecturers to manage the emotional labor of pedagogical transformation: the student resistance, the confusion, the gradual breakthroughs that cannot be rushed. Future research should adopt longitudinal designs tracking PPG graduates into their early teaching years to assess durability of competency gains, multi institutional comparisons across Indonesia's diverse higher education landscape, and investigation of hybrid models sustaining reflective communities beyond the intensive semester. Ultimately, deep learning pedagogy should be valued not solely for its measurable outcomes in literacy and numeracy, but for its humanizing potential—

creating spaces where prospective teachers like Rina and Andi can move from stuttering uncertainty toward professional voice, from procedural compliance toward authentic educational agency.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used ChatGPT (OpenAI) to assist in language editing, text organization, and improving the clarity of academic writing. After using this tool, the author(s) carefully reviewed, revised, and validated the content as needed and take full responsibility for the accuracy, integrity, and originality of the final manuscript.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the institutions that supported the completion of this research. Special appreciation is extended to Universitas Pasundan for providing academic support, research facilities, and an academic environment that facilitated the successful implementation of this study within the Teacher Professional Education (PPG) program.

The authors also extend their appreciation to colleagues, academic peers, and all participants involved in this research for their valuable contributions, constructive discussions, and feedback throughout the research and manuscript preparation process. The collaboration and commitment of the research team Arifin Ahmad, Moh. Nurhadi, and Dahlia Rineva have been essential in ensuring the successful completion of this study.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Anam, C., Wiradharma, G., Anggrini, C. C. D., & Sudarwo, R. (2022). Analisis Kompetisi Guru Sekolah Dasar Di Provinsi Nusa Tenggara Barat. *Journal of Administration and Educational Management (Alignment)*, *5*(2), 253–265. https://doi.org/10.31539/alignment.v5i2.4552

Anthonysamy, L., Sugendran, P., Wei, L. O., & Hoon, T. S. (2024). An improved metacognitive competency framework to inculcate analytical thinking among university students. *Education and Information Technologies 2024 29:17*, *29*(17), 22475–22497. https://doi.org/10.1007/s1063902412678z

Baeten, M., Dochy, F., & Struyven, K. (2020). Using student centred learning environments to stimulate deep approaches to learning. *Educational Research Review*, *30*, 100334.

Bhuttah, T. M., Xusheng, Q., Abid, M. N., & Sharma, S. (2024). Enhancing student critical thinking and learning outcomes through innovative pedagogical approaches in higher education: the mediating role of inclusive leadership. *Scientific Reports 2024 14:1*, *14*(1), 24362 . https://doi.org/10.1038/s41598024753790

Borji, V., Radmehr, F., & Font, V. (2021). The impact of procedural and conceptual teaching on students' mathematical performance over time. *International Journal of Mathematical*

Education in Science and Technology, *52*(3), 404–426. https://doi.org/10.1080/0020739X.2019.1688404

Chan, C. K. Y., & Yuen, M. (2021). Students' approaches to learning in higher education. *Active Learning in Higher Education*, *22*(2), 95–108.

Chan, J. Y. C., Closser, A. H., Ngo, V., Smith, H., Liu, A. S., & Ottmar, E. (2023). Examining shifts in conceptual knowledge, procedural knowledge and procedural flexibility in the context of two game based technologies. *Journal of Computer Assisted Learning*, *39*(4), 1274–1289. https://doi.org/10.1111/jcal.12798

Chang Tik, C. (2023). Collaborative spaces: investigating the relationships between students' group based learning and lecturers' approaches. *Educational Research*, *65*(4), 409–427. https://doi.org/10.1080/00131881.2023.2256747

Dahlan, J. A., Juandi, D., Yogaswara, A., & Kurniasih, D. (2023). Developing Mathematics Teaching Materials Based on Numeracy Literacy for Junior High School Mathematics Teachers in West Bandung Regency. *Transformasi Jurnal Pengabdian Masyarakat*, *19*(2), 237–249. https://doi.org/10.20414/transformasi.v19i2.8294

Darling Hammond, L., Hyler, M. E., & Gardner, M. (2020). *Effective Teacher Professional Development*. Learning Policy Institute.

Dewi, R. C., & Rusman, R. (2025). Exploring Cross Curriculum Numeracy Understanding and Implementation in Santa Angela Teachers. *Inovasi Kurikulum*, *22*(1), 367–390. https://doi.org/10.17509/jik.v22i1.78561

Fullan, M., Quinn, J., & McEachen, J. (2020). *Deep Learning: Engage the World, Change the World*. Corwin Press.

Fyfe, E. R., Rittle Johnson, B., & DeCaro, M. S. (2021). The role of conceptual and procedural knowledge in mathematics learning. *Journal of Educational Psychology*, *113*(5), 915–930.

Hua, M., Wang, L., & Li, J. (2023). The impact of self directed learning experience and course experience on learning satisfaction of university students in blended learning environments: the mediating role of deep and surface learning approach. *Frontiers in Psychology*, *14*, 1278827. https://doi.org/10.3389/FPSYG.2023.1278827/FULL

Iannone, P., Czichowsky, C., & Ruf, J. (2020). The impact of high stakes oral performance assessment on students' approaches to learning: a case study. *Educational Studies in Mathematics 2020 103:3*, *103*(3), 313–337. https://doi.org/10.1007/S10649020099374

Killam, L. A., & Camargo-Plazas, P. (2021). Revisioning Assessment and Evaluation in Nursing Education Through Critical Caring Pedagogy. *Advances in Nursing Science*, *45*(1), E15–E30. https://doi.org/10.1097/ans.0000000000000382

Kim, Y., Park, H., & Cozart, J. (2021). Metacognitive reflection and academic writing development in higher education. *Journal of Writing Research*, *13*(1), 45–67.

Limpo, T., & Alves, R. A. (2022). Self regulation strategies in academic writing. *Reading and Writing*, *35*(4), 913–935.

Liu, Z., Guo, H., Zhou, Z., Ma, F., & Zeng, Y. (2025). How creative self efficacy influences problem solving skills in engineering education: the dual mediating role of critical thinking and metacognition. *BMC Psychology 2025 13:1*, *13*(1), 1278 . https://doi.org/10.1186/S4035902503630Y

Merkebu, J., Veen, M., Hosseini, S., & Varpio, L. (2024). The case for metacognitive reflection: a theory integrative review with implications for medical education. *Advances in Health Sciences Education 2024 29:4*, *29*(4), 1481–1500. https://doi.org/10.1007/S10459023103102

Mickwitz, Å., & Suojala, M. (2020). Learner autonomy, self regulation skills and self efficacy beliefs How can students' academic writing skills be supported? *Language Learning in Higher Education*, *10*(2), 381–402. https://doi.org/10.1515/cercles20202026

Murni, V., Nendi, F., Jundu, R., Men, F. E., Pantaleon, K. V, Jehadus, E., & Jeramat, E. (2022). Pelatihan Penyusunan Instrumen Asesmen Kompetensi Minimum (AKM) Di SMK Bina Kusuma Ruteng. *Jurnal Kreativitas Pengabdian Kepada Masyarakat (Pkm)*, *5*(8), 2694–2715. https://doi.org/10.33024/jkpm.v5i8.6031

Nwagwu, W. E. (2024). Mapping the field of global research on data literacy: Key and emerging issues and the library connection. *IFLA Journal*, *50*(3), 491–510. https://doi.org/10.1177/03400352241257669;WEBSITE:WEBSITE:SAGE;REQUESTEDJOURNAL:JOURNAL:IFLB;JOURNAL:JOURNAL:IFLB;WGROUP:STRING:PUBLICATION

Qazi, A. G., & Pachler, N. (2025). Conceptualising a data analytics framework to support targeted teacher professional development. *Professional Development in Education*, *51*(3), 495–518. https://doi.org/10.1080/19415257.2024.2422066

Raffaghelli, J. E., & Stewart, B. (2020). Centering complexity in 'educators' data literacy' to support future practices in faculty development: a systematic review of the literature. *Teaching in Higher Education*, *25*(4), 435–455. https://doi.org/10.1080/13562517.2019.1696301

Rittle Johnson, B., Schneider, M., & Star, J. R. (2021). Not a one way street: Bidirectional relations between conceptual and procedural knowledge. *Educational Psychology Review*, *33*(4), 1–26.

Rusman, T., Nurdin, N., Rahmawati, F., & Wulan, M. N. (2023). Pelatihan Pembuatan Media Pembelajaran Digital Berbasis Literasi Dan Numerasi Bagi Guru Sekolah Dasar. *Jurnal Pengabdian Sosial Indonesia*, *3*(2), 109–114. https://doi.org/10.23960/jpsi/v3i2.109114

Seppanen, M. (2023). The quality of argumentation and metacognitive reflection in engineering co Design. *European Journal of Engineering Education*, *48*(1), 75–90. https://doi.org/10.1080/03043797.2022.2054314

Shen, B., & Bai, B. (2024). Enhancing Chinese university students' writing performance and self regulated learning (SRL) writing strategy use through a strategy based intervention. *System*, *122*, 103249. https://doi.org/10.1016/j.system.2024.103249

Sulistyani, N., & Kusumawardana, A. S. (2022). Pendampingan Penyusunan Modul Numerasi Berorientasi Asesmen Kompetensi Minimum Di Sekolah Dasar. *JMM (Jurnal Masyarakat Mandiri)*, *6*(1), 464. https://doi.org/10.31764/jmm.v6i1.6431

Teng, M. F., & Yue, M. (2022). Metacognitive writing strategies, critical thinking skills, and academic writing performance: A structural equation modeling approach. *Metacognition and Learning 2022 18:1*, *18*(1), 237–260. https://doi.org/10.1007/s11409022093285

Yang, L. (Francoise), & Zhang, L. J. (2023). Self regulation and student engagement with feedback: The case of Chinese EFL student writers. *Journal of English for Academic Purposes*, *63*, 101226. https://doi.org/10.1016/j.jeap.2023.101226

Zohar, A., & Ben Ari, G. (2022). Teachers' knowledge and professional development for metacognitive instruction in the context of higher order thinking. *Metacognition and Learning*, *17*(3), 855–895. https://doi.org/10.1007/S11409022093101/METRICS