



# Synergy of Pedagogical Content Knowledge, Digital Literacy, and Instructional Design Skills in Preparing Quality Elementary Teachers for Impactful Learning

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**Abstract:** This study examines how Pedagogical Content Knowledge (PCK), digital literacy, and instructional design skills synergistically influence perceived impactful learning among elementary teacher education students. A sequential explanatory mixed-methods design was employed: quantitative data from 222 students via surveys, followed by qualitative data from 15 students through focus group interviews. Quantitative results show PCK and instructional design skills collectively explain 70% of variance in impactful learning, with balanced and strong effects, while digital literacy functions as a supporting enabler rather than primary determinant. Qualitative findings identify six facilitating factors, eight barriers, and seven moderators that contextualize competency integration patterns. The study proposes three conceptual frameworks Synergistic Competency Framework, Grade Responsive Pedagogy Framework, and Pedagogy Primacy Framework integrated within the Subject-Specific Deep Learning Pedagogy (SSDLP) model, which positions PCK as the foundational layer for technology-enhanced instruction. Conclusions emphasize that impactful learning emerges when pedagogical foundations precede technological integration, with field experience and intrinsic motivation as critical catalysts. Teacher education programs should prioritize systematic PCK development, positioning digital literacy as complementary infrastructure.

**Keywords:** Digital literacy; Elementary education; Impactful learning; Instructional design; Pedagogical content knowledge

## Introduction

Elementary education constitutes the foundational stage of formal learning, establishing critical cognitive, social, and emotional competencies that profoundly influence students' lifelong learning trajectories and academic success. During these formative years, children develop fundamental literacy and numeracy skills, cultivate dispositions toward learning, and establish patterns of engagement with knowledge that persist throughout their educational journeys (Chand, 2025). The quality of instruction at this pivotal stage is fundamentally determined by teacher competence, particularly their capacity to integrate deep content

knowledge with developmentally appropriate pedagogical strategies specifically calibrated to young learners' unique characteristics and needs (Kleickmann et al., 2023).

In contemporary educational landscapes, pre-service elementary teachers confront increasingly complex professional demands that extend far beyond traditional pedagogical preparation (Nurhairani et al., 2025). They must master foundational pedagogical competencies while simultaneously developing proficiency in digital technologies that progressively mediate learning experiences, navigate diverse and inclusive classrooms with heterogeneous student populations, and respond to rapidly evolving

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educational policies and curriculum frameworks (Schmid et al., 2021). This multifaceted preparation occurs within a broader context of educational transformation, where digital technologies, pedagogical innovations, and changing societal expectations converge to reshape fundamental assumptions about effective teaching and learning (Bozkurt & Zawacki-Richter, 2021).

Pedagogical Content Knowledge (PCK), originally conceptualized by Shulman (1987) the distinctive professional knowledge that distinguishes expert teachers from content specialists, represents the intersection of subject matter expertise and pedagogical understanding. PCK encompasses knowledge of how to represent specific content to make it comprehensible to learners, understanding of what makes particular topics easy or difficult for students, awareness of common misconceptions and strategies to address them, and selection of instructional approaches most effective for teaching specific content to particular learners (Star, 2023). This specialized knowledge domain transcends simple aggregation of content knowledge and general pedagogical principles, constituting instead a unique synthesis that enables teachers to transform subject matter into forms genuinely accessible to diverse learners across varying developmental stages (Evitasiari et al., 2025).

Contemporary scholarship continues to affirm PCK's critical and enduring role in determining instructional quality and student learning outcomes across diverse educational contexts, subject areas, and grade levels (Depaepe et al., 2023). Recent meta-analytic evidence demonstrates consistent positive relationships between teacher PCK and student achievement, with effect sizes varying by subject domain, measurement approaches, and contextual factors (Liu et al., 2024). However, the nature of PCK itself has evolved, with researchers recognizing its dynamic, context-dependent characteristics rather than viewing it as static knowledge to be acquired once and applied uniformly (Carlson et al., 2019). This reconceptualization acknowledges that PCK develops continuously through practice, reflection, and engagement with students in authentic teaching contexts, particularly during formative pre-service and early career stages (Grossman, 2022).

The accelerated digitalization of education, intensified dramatically by the global COVID-19 pandemic's disruption of traditional schooling, has raised fundamental questions about whether conventional pedagogical competencies remain sufficient or require substantial reconceptualization to incorporate technological dimensions (Pettersson, 2021). Digital technologies have transitioned from supplementary tools to integral components of educational infrastructure, fundamentally altering how

content is accessed, represented, communicated, and assessed (Kultsum, 2017). This transformation has prompted extensive debate regarding the knowledge and skills contemporary teachers require, with some scholars arguing for technology integration as central to modern pedagogical competence Koehler et al. (2013) while others maintain that technological proficiency without robust pedagogical foundations proves insufficient or counterproductive (Clark & Mayer, 2023).

Digital literacy has emerged as an essential, multidimensional competency for 21st-century educators, encompassing far more than technical operational skills (Rachmadtullah et al., 2025). Contemporary conceptions of digital literacy integrate technical proficiency with critical evaluation of digital information sources, understanding of digital media construction and bias, ethical and responsible technology use, creative application of digital tools to enhance learning, and capacity to teach students themselves to navigate digital environments safely and productively (Vuorikari et al., 2016). For teachers specifically, digital literacy extends to pedagogical applications: selecting appropriate technologies aligned with learning objectives, designing digital learning experiences that promote active engagement rather than passive consumption, facilitating online collaboration and communication, and assessing learning in technology-mediated environments (Ng & Zerouali, 2022).

Research examining digital literacy's role in teaching effectiveness has produced nuanced, sometimes contradictory findings (Utaminingsih et al., 2023). While numerous studies document positive associations between teacher digital competence and instructional innovation, student engagement, and learning outcomes in technology-rich environments, these relationships appear substantially moderated by contextual factors including infrastructure availability, institutional support, and pedagogical integration approaches (Soomro et al., 2023). Meta analytic evidence suggests that technology's educational impact depends less on technological sophistication per se than on how thoughtfully technology is integrated with sound pedagogical principles and deep content understanding (Martin & Bolliger, 2018). These findings raise critical questions about digital literacy's relative importance compared to foundational pedagogical and content knowledge, particularly in contexts where technological infrastructure remains limited or unreliable.

Instructional design skills constitute a third critical dimension of teacher competence, representing the systematic capabilities for planning, organizing, sequencing, and structuring learning experiences to facilitate meaningful understanding and transfer (Suwarjo et al., 2022). Grounded in established design

frameworks emphasizing backward design from desired learning outcomes, constructive alignment among objectives, activities, and assessments, and responsive adaptation to learner needs and contextual constraints (Wiggins & McTighe, 2024), instructional design transcends mere technical application of design templates. Contemporary conceptualizations position instructional design as creative problem-solving requiring integration of understanding about learners, content structures, contextual affordances and constraints, and pedagogical strategies (Taufikurrahman, 2021).

Impactful learning, the central outcome of interest in this study, is conceptualized as pre-service teachers' capacity to design and deliver instruction that demonstrably influences student cognitive engagement, deep understanding, and lasting knowledge retention (Eliaumra et al., 2024). Unlike traditional measures of teaching effectiveness that emphasize behavioral compliance or surface-level performance, impactful learning focuses on meaningful educational experiences that transform student thinking, foster active knowledge construction, and promote transferable understanding applicable beyond immediate instructional contexts (Hattie, 2023). In the context of pre-service teacher education, impactful learning is operationalized through self-reported assessments of confidence and competence in creating learning experiences that engage elementary students meaningfully, address diverse learning needs, and produce observable academic progress. This emphasis on perceived capacity is grounded in substantial research demonstrating that pre-service teachers' self-efficacy and metacognitive awareness of their instructional impact significantly predict their subsequent classroom effectiveness and professional development trajectories (Ashari et al., 2025). Importantly, this conceptualization recognizes that impactful learning emerges not from isolated competencies but from synergistic integration of pedagogical knowledge, technological proficiency, and design capabilities adapted responsively to learner needs and contextual realities.

Recent research demonstrates that teachers with robust instructional design capabilities produce more coherent, purposeful learning experiences characterized by clear learning progressions, meaningful cognitive engagement, and authentic assessment aligned with learning goals (Newell et al., 2024). Effective instructional design proves particularly consequential in elementary education, where developmentally appropriate sequencing, integration across subject boundaries, and scaffolding of increasingly complex concepts establish foundations for subsequent learning (Phillips, 2016). However, instructional design skills remain underdeveloped in many teacher preparation

programs, which often emphasize theoretical knowledge over practical design competencies or treat lesson planning as administrative compliance rather than sophisticated professional practice (Reiser & Dempsey, 2024).

Despite growing recognition of these three competency domains PCK, digital literacy, and instructional design skills as essential for contemporary teaching, three critical gaps persist in understanding how they interact synergistically to shape impactful learning. First, most existing research investigates these competencies in isolation, examining relationships between individual competencies and various outcomes without considering how multiple competencies combine or interact (Bellibaş & Gümüş, 2023). Studies that do examine multiple competencies simultaneously tend to employ additive models assuming independent effects rather than investigating interactive, synergistic relationships where competencies mutually reinforce or amplify one another's contributions. Second, the limited research examining multiple competencies simultaneously focuses predominantly on in-service teachers with established practices rather than pre-service teachers undergoing formative professional development (König et al., 2020). This focus on practicing teachers, while valuable, provides limited insight into how teacher education programs might most effectively cultivate integrated competency development during pre-service preparation when foundational professional identities and practices are being formed. Third, the majority of research on teacher competencies originates from technologically advanced contexts in North America, Western Europe, and East Asia, where reliable technological infrastructure, substantial educational technology investment, and widespread digital access characterize educational environments (Zhao & Watterston, 2021). Findings from these contexts may not transfer readily to developing nations where infrastructure limitations, resource constraints, large class sizes, and diverse socioeconomic conditions present distinctly different challenges and opportunities. The assumption underlying much educational technology research that technological access and integration represent unmitigated progress requires critical examination in contexts where technology may be unavailable, unreliable, or inappropriate for particular learning goals or developmental stages.

This study addresses these three critical gaps simultaneously, offering several distinctive contributions that advance understanding of elementary teacher preparation. First, unlike prior research examining competencies in isolation, this study investigates synergistic interactions among PCK, digital literacy, and instructional design skills, revealing how

these competencies combine to influence impactful learning rather than simply adding their individual effects. Second, by focusing specifically on pre-service teachers in formative stages of professional development, the research provides insights directly applicable to teacher education program design, curriculum sequencing, and pedagogical approaches for cultivating integrated competency development. Third, by conducting research in Indonesia's heterogeneous educational context characterized by dramatic urban-rural disparities in technological infrastructure the study examines competency integration across both technology-rich and technology limited environments within a single institutional setting. This contextual diversity enables investigation of a question with profound implications for global teacher education: which competencies prove essential for impactful learning when technological infrastructure cannot be assumed? Understanding competency hierarchies and interaction patterns in contexts where not all competencies can be equally developed provides crucial guidance for teacher education programs serving graduates who will teach across vastly different resource environments.

The Indonesian context presents particularly salient considerations for investigating teacher competency integration, offering important insights with broader implications for educational development globally (Dhaniaputri & Acuña, 2025). Indonesian elementary schools exhibit substantial heterogeneity in technological infrastructure, pedagogical approaches, and resource availability, with pronounced urban rural disparities creating dramatically different teaching and learning environments (Efendi & Muliadi, 2023). Urban schools, particularly in major cities, increasingly feature digital technologies, internet connectivity, and resources supporting technology integration, while rural and remote schools frequently lack electricity, internet access, or basic technological infrastructure. This stark variability means Indonesian pre-service teachers must develop competencies effective across radically different contexts, including resource-constrained settings where sophisticated technology remains unavailable or unreliable.

This contextual reality necessitates understanding not simply whether PCK, digital literacy, and instructional design skills matter for impactful learning a question to which the answer appears affirmatively established but rather their relative importance, how they interact synergistically, and which competencies prove most essential when not all can be equally developed. If digital literacy's contribution to impactful learning depends heavily on technological infrastructure, its prioritization in teacher education may prove problematic in contexts where graduates will

teach without reliable technology. Conversely, if PCK and instructional design skills contribute substantially to impactful learning independent of technological mediation, these competencies warrant prioritization regardless of technological context. These questions carry significant implications for teacher education program design, resource allocation, and curriculum emphasis.

Moreover, understanding factors that facilitate or inhibit competency integration proves crucial for designing effective teacher preparation. Pre-service teachers develop competencies not in isolation but within complex ecosystems encompassing institutional supports, faculty modeling, peer collaboration, field experiences, personal motivations, and contextual constraints (Lubis & Ikhsan, 2015). Identifying which factors most powerfully shape competency development enables teacher education programs to structure experiences, allocate resources, and provide supports strategically aligned with effective preparation. Similarly, understanding strategies and mindsets that enable pre-service teachers to integrate competencies effectively despite constraints illuminates pathways toward resilient, adaptive professional practice capable of generating impactful learning across diverse circumstances.

This study addresses these critical gaps by investigating the synergistic relationships among PCK, digital literacy, and instructional design skills in shaping impactful learning among elementary teacher education students at Universitas Muhammadiyah Muara Bungo, Indonesia. This institution was purposively selected because it exemplifies the heterogeneity characteristic of Indonesian teacher education contexts: its student body comprises both urban and rural pre-service teachers, with significant proportions originating from remote areas with minimal technological infrastructure, limited internet connectivity, and resource constrained schools. Simultaneously, the university itself has recently invested in digital learning facilities, computer laboratories, and educational technology resources, creating a dual reality where students experience technology enhanced instruction on campus while recognizing that many will teach in schools lacking such resources. This institutional context enables examination of competency integration across varying technological contexts within a single setting, providing insights into how pre-service teachers develop adaptive competencies effective in both resource rich and resource constrained environments a critical capability for Indonesian teachers and, increasingly, for educators globally as technological inequality persists despite widespread digitalization.

The research examines four interconnected dimensions: First, it investigates the individual influence

of each competency PCK, digital literacy, and instructional design skills on impactful learning, establishing baseline understanding of each competency's contribution. Second, it examines paired and collective relationships among competencies, determining how they interact synergistically and whether certain combinations prove particularly powerful. Third, it assesses the relative strength of each competency's contribution when examined simultaneously, revealing hierarchies of importance with implications for teacher education priorities. Fourth, it identifies factors that facilitate or inhibit competency integration and strategies that enable effective development despite contextual constraints, providing actionable insights for program improvement.

Through mixed-methods sequential explanatory design combining quantitative survey data from 222 students with qualitative focus group interviews of 15 students, this research provides comprehensive, contextualized understanding of how pre-service elementary teachers develop and integrate essential professional competencies for impactful learning. The quantitative phase establishes patterns, relationships, and relative importance across the full sample, while the qualitative phase illuminates mechanisms, experiences, and contextual factors that quantitative data alone cannot capture (Mardiyanti, 2024; Ermayanti et al., 2023). This integrated approach yields both generalizable findings about competency relationships and rich, nuanced understanding of the lived experiences through which pre-service teachers develop these competencies.

This research aims to make several significant contributions. Theoretically, the study seeks to propose the Subject Specific Deep Learning Pedagogy (SSDLP) model as a new conceptual framework integrating PCK, digital literacy, and instructional design within elementary teacher education, and to explore emergent theoretical perspectives on competency synergy, pedagogical prioritization, and context-responsive teaching that may advance scholarly understanding of teacher preparation. Practically, findings aim to inform teacher education program design, particularly regarding competency prioritization in resource constrained contexts, pedagogical approaches for cultivating integrated competency development, and support structures facilitating integration despite infrastructure limitations. As educational systems globally grapple with integrating digital technologies while maintaining pedagogical quality, understanding how foundational competencies interact with digital literacy becomes increasingly critical. Ultimately, this research seeks to advance fundamental understanding of what constitutes effective elementary teacher

preparation in an era of educational transformation, technological change, and persistent inequalities in educational resources and opportunities, with implications extending beyond Indonesia to diverse global contexts confronting similar challenges.

## Method

This research employs a mixed-methods sequential explanatory design integrating quantitative and qualitative approaches to comprehensively understand the synergy between Pedagogical Content Knowledge (PCK), digital literacy, and instructional design skills in shaping impactful learning. The design begins with quantitative data collection and analysis to identify patterns and relationships, followed by qualitative exploration to explain mechanisms underlying quantitative findings (Creswell, 2017; Sholeh et al., 2025). The study was conducted at Universitas Muhammadiyah Muara Bungo, Jambi Province, from August to October 2025, with surveys distributed August 12–September 12 and focus group discussions held October 6, 2025. Figure 1 presents the research flow illustrating sequential integration of both phases.



Figure 1. Research flow diagram

The quantitative phase employed total sampling encompassing all 222 PGSD students at Universitas Muhammadiyah Muara Bungo. This approach ensures complete population representation and minimizes sampling bias (Widiyawati et al., 2023). Of 222 distributed questionnaires, 220 were returned complete (99.1% response rate), with two excluded due to >20% missing data. This high response rate was achieved through WhatsApp reminders, class representative follow-ups, and administrative coordination. While total sampling minimizes sampling error, potential non-response bias was assessed by comparing early versus late respondents across demographic characteristics (gender, semester, GPA), revealing no significant differences ( $p > 0.05$ ), thus supporting sample representativeness.

For the qualitative phase, purposive sampling selected 15 final-semester students meeting criteria: (1) completed microteaching, (2) completed learning planning courses, (3) participated in PPL II field practice, and (4) willingness to participate. From 28 eligible students, 15 were selected for maximum variation in field practice settings (urban/rural), technology access, and digital literacy confidence. Participants were

divided into three focus groups of five participants each to facilitate intensive, balanced discussions.

Quantitative data were collected via Google Forms distributed through WhatsApp groups. The questionnaire measured four constructs using five-point Likert scales (1=Strongly Disagree to 5=Strongly Agree): Impactful Learning (10 items, adapted from Hattie, 2023), Pedagogical Content Knowledge (9 items, from Shulman, 1987), Digital Literacy (11 items, from Vuorikari et al., 2016), and Instructional Design Skills (10 items, from Wiggins & McTighe, 2024). Pilot testing with 30 students from a neighboring institution confirmed adequate reliability (Cronbach's  $\alpha = 0.83\text{--}0.89$ ) and validity (factor loadings  $> 0.70$ ).

Qualitative data were collected through three focus group discussions, each with five participants lasting 90 minutes in a university seminar room. Sessions began with ice-breaking and ground rules, then proceeded with semi-structured questions like "How do you integrate pedagogical knowledge with technology during field teaching?" and "What challenges did you face using digital tools in elementary classrooms?" All sessions were audio-recorded with informed consent and transcribed verbatim by a professional transcriptionist. The primary researcher maintained field notes documenting non-verbal communication, group dynamics, and preliminary observations.

Quantitative analysis employed SEM-PLS using SmartPLS 4.1.1.4, selected for its ability to simultaneously examine measurement and structural models, suitability for exploratory theory development, and robustness with non-normal distributions (Hair et al., 2021). A reflective measurement model was used, wherein indicators are manifestations of underlying constructs appropriate for Likert-scale perceptual items (Jarvis et al., 2003).

Analysis followed seven systematic steps (Hair et al., 2019): (1) Model specification of hypothesized relationships based on theoretical frameworks; (2) Outer model evaluation assessing indicator reliability (factor loadings  $\lambda > 0.70$ ), internal consistency (Composite Reliability  $> 0.70$ ), convergent validity ( $AVE > 0.50$  calculated as  $AVE = \frac{\sum \lambda_i^2}{\sum \lambda_i^2 + \sum \text{var}(\epsilon_i)}$ ), and discriminant validity (Fornell-Larcker criterion and HTMT  $< 0.85$ ); (3) Inner model evaluation examining path coefficients ( $\beta$ ),  $R^2$  (variance explained), and effect sizes ( $f^2$ ) calculated as  $f^2 = \frac{R^2_{\text{included}} - R^2_{\text{excluded}}}{1 - R^2_{\text{included}}}$ ; (4) Bootstrapping with 5,000 resamples for significance testing ( $p < 0.05$ ); (5) Model fit assessment using SRMR  $< 0.08$  and NFI  $> 0.90$ ; (6) Predictive relevance via Stone-Geisser's  $Q^2$  through blindfolding; (7) Hypothesis testing based on path coefficient significance.

## Result and Discussion

### Results

#### Quantitative Findings

Preliminary bivariate correlation analysis revealed strong individual relationships between each competency and impactful learning: PCK ( $r=0.784$ ,  $p<0.001$ ), instructional design skills ( $r=0.795$ ,  $p<0.001$ ), and digital literacy ( $r=0.749$ ,  $p<0.001$ ). All three variables operated at high categorical levels (PCK:  $M=4.11$ ,  $SD=0.52$ ; Digital Literacy:  $M=4.03$ ,  $SD=0.48$ ; Instructional Design Skills:  $M=4.04$ ,  $SD=0.50$ ), indicating that PGSD students generally perceived themselves as competent across these domains.

However, the high bivariate correlations raised concerns about potential multicollinearity when examining these competencies simultaneously in the structural model. Variance Inflation Factor (VIF) analysis revealed moderate collinearity: PCK (VIF=2.87), instructional design skills (VIF=3.12), and digital literacy (VIF=2.54). While these values remain below the critical threshold of 5.0 indicating severe multicollinearity (Hair et al., 2021), they confirm substantial conceptual overlap among competencies—an expected finding given that effective teaching integrates multiple knowledge domains. The moderate VIF values validate the use of all three predictors simultaneously while acknowledging their interconnectedness.

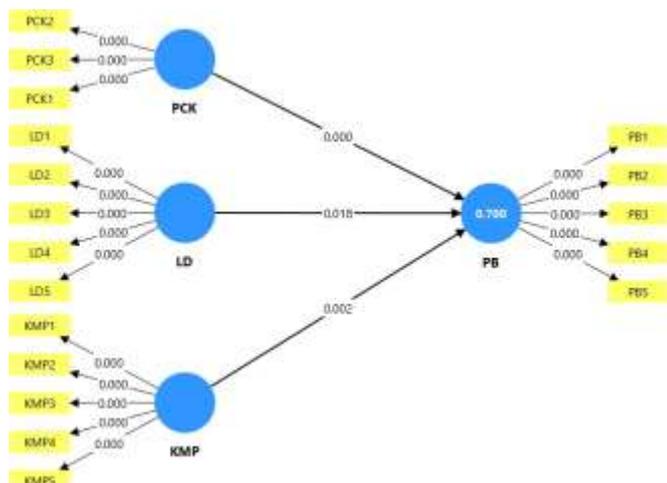
The structural equation model examining the combined influence of all three competencies explained 70% of variance in impactful learning ( $R^2=0.70$ ), indicating substantial predictive power. Table 1 presents the complete path analysis results. When examined simultaneously in the path model, the standardized path coefficients revealed a nuanced hierarchy: PCK ( $\beta=0.344$ ,  $t=5.12$ ,  $p<0.000$ ) and instructional design skills ( $\beta=0.347$ ,  $t=5.28$ ,  $p<0.001$ ) maintained balanced and relatively equivalent influence, while digital literacy contributed more modestly ( $\beta=0.205$ ,  $t=2.89$ ,  $p=0.002$ ). The reduction in individual  $\beta$  values compared to bivariate correlations reflects standard suppression effects in multiple regression, where shared variance among correlated predictors is partitioned, revealing each variable's unique contribution beyond the others. Effect size analysis ( $f^2$ ) confirmed that PCK ( $f^2=0.18$ ) and instructional design skills ( $f^2=0.19$ ) exerted medium effects, while digital literacy demonstrated a small effect ( $f^2=0.06$ ). This pattern held consistently across alternative model specifications with different variable ordering, suggesting robust relationships independent of modeling decisions.

**Table 1.** Structural Model Path Coefficients and Model Fit Statistics

| Path                                      | $\beta$ | SE    | t-value | p-value | $f^2$ | VIF  |
|---|---------|-------|---------|---------|-------|------|
| PCK → Impactful Learning                  | 0.344   | 0.067 | 5.12    | <0.000  | 0.18  | 2.87 |
| Instructional Design → Impactful Learning | 0.347   | 0.066 | 5.28    | <0.001  | 0.19  | 3.12 |
| Digital Literacy → Impactful Learning     | 0.205   | 0.071 | 2.89    | 0.002   | 0.06  | 2.54 |

Model Fit:  $R^2 = 0.70$ ;  $Q^2 = 0.52$ ; SRMR = 0.065; NFI = 0.92

Note. Bootstrap with 5,000 resamples.  $\beta$  = standardized path coefficient; SE = standard error;  $f^2$  = effect size; VIF = variance inflation factor.



**Figure 2.** Structural model diagram showing path coefficients

Measurement model quality indicators confirmed adequate reliability and validity. All constructs demonstrated high internal consistency (Composite Reliability: PCK = 0.89, Digital Literacy = 0.91, Instructional Design = 0.88, Impactful Learning = 0.90) and convergent validity (AVE: PCK=0.57, Digital Literacy=0.61, Instructional Design=0.55, Impactful Learning=0.59). Discriminant validity was established through both Fornell-Larcker criterion (square root of each construct's AVE exceeded its correlations with other constructs) and HTMT ratios (all<0.85), confirming that despite conceptual overlap, the four constructs represent empirically distinct domains.

*Qualitative Findings*

Qualitative analysis of focus group discussions involving 15 purposively selected participants identified a comprehensive ecosystem of factors influencing competency integration, organized into three categories.

Supporting Factors (6 categories, 72 total coded segments): Field experience emerged as most salient (referenced by 100% of participants, 18 coded segments), followed by intrinsic motivation (100%, 15 segments), faculty modeling (93%, 12 segments), campus technology facilities (93%, 11 segments), microteaching practice (87%, 10 segments), and peer support (47%, 6 segments). Field experience functioned as a transformative context shifting students from abstract theoretical understanding to grounded practical wisdom about technology's actual role in elementary

classrooms. As one participant articulated: "Field practice completely changed my perspective. I entered thinking digital tools were essential for good teaching. I left understanding that strong pedagogy matters most, with technology serving as one option among many." Intrinsic motivation focused specifically on student learning impact rather than personal achievement or external validation demonstrated greater resilience against obstacles encountered during field teaching.

Inhibiting Factors (8 categories, 89 total coded segments): Infrastructure limitations emerged as universal (100%, 22 segments), alongside technology access gaps (80%, 15 segments), technical failure risks (80%, 12 segments), limited digital competence among mentor teachers (73%, 11 segments), preparation time constraints (67%, 10 segments), practitioner inconsistency (67%, 8 segments), social resistance from parents or administrators (60%, 7 segments), and cost limitations (40%, 4 segments). Infrastructure barriers proved universal every participant encountered schools with unreliable internet connectivity, insufficient student devices, and aging equipment. Notably, these infrastructure constraints did not paralyze students but instead prompted creative pedagogical adaptations. One participant reflected: "When the internet failed during my science lesson, I realized I could still teach the concept effectively using hands-on materials. The technology would have been nice, but it wasn't essential."

Moderating Factors (7 categories, 97 total coded segments): Balanced learning approaches emphasizing pedagogical principles over technological tools (100%, 18 segments), content prioritization focusing on learning objectives rather than delivery methods (100%, 16 segments), field learning insights gained through authentic teaching practice (100%, 15 segments), developmental appropriateness consideration for elementary learners' cognitive stages (93%, 14 segments), teacher creativity and adaptability in resource-constrained contexts (87%, 13 segments), technology effectiveness evaluation based on learning outcomes (80%, 12 segments), and backup planning for technology failures (73%, 9 segments). These factors functioned as cognitive strategies and philosophical orientations that amplified supporting factors' positive influence while minimizing inhibiting factors' negative impact.

## Discussion

### *Integration of Competencies*

The findings reveal that impactful learning in elementary education emerges not from isolated competencies but from their synergistic interaction, a pattern consistent with contemporary perspectives on teacher knowledge integration (Depaepe et al., 2023). PCK and instructional design skills demonstrated comparable influence ( $\beta = 0.344$  and  $0.347$  respectively), suggesting they function as complementary rather than hierarchical competencies. This finding aligns with Magnusson et al.'s (1999) framework positioning PCK as comprising orientation toward teaching, knowledge of student learning, curricular knowledge, instructional strategies, and assessment knowledge all components requiring systematic design capacity for effective implementation. Recent research by Carlson et al. (2019) documented that PCK develops dynamically through cycles of planning, enactment, and reflection, processes inherently requiring instructional design competence. Our findings extend this scholarship by demonstrating empirically that PCK's effectiveness in producing impactful learning multiplies when paired with structured instructional design capabilities.

PCK provides deep pedagogical-content understanding ("what and how to teach specific content to particular learners"), while instructional design skills translate this understanding into systematic, coherent learning experiences ("how to operationalize teaching through structured planning"). This complementarity challenges assumptions positioning technology as foundational to contemporary teaching effectiveness. As Shulman (1987) noted foundational, "Pedagogical content knowledge embodies the aspects of content most germane to its teachability" a principle our findings suggest remains valid even in digitally mediated contexts. The content and its pedagogically responsive teaching matter fundamentally; the medium through which content is delivered serves supportive rather than determinative functions.

The modest yet statistically significant contribution of digital literacy ( $\beta=0.205$ ,  $p=0.002$ ) warrants careful interpretation. Digital literacy remained important all three competencies significantly predicted impactful learning but its relative influence diminished substantially when examined alongside stronger pedagogical competencies. This pattern aligns with Clark et al. (2023) comprehensive meta-analysis of multimedia learning demonstrating that while instructional method and media choice affect learning, underlying pedagogical strategy remains the primary determinant of effectiveness. Participants did not dismiss technology; rather, they developed pragmatic perspectives recognizing technology as a tool serving pedagogy rather than an end in itself. This represents

what might be termed "pedagogically grounded digital literacy" the capacity to deploy technology strategically within coherent pedagogical frameworks rather than for its own sake or due to technological enthusiasm unmoored from learning objectives.

### *Ecosystem Dynamics*

The ecosystem analysis illuminates why competency development follows neither linear nor technologically deterministic pathways. Field experience functioned as a transformative crucible where idealistic assumptions about technology's educational role confronted classroom realities. Participants typically entered field experience enthusiastic about technological solutions; they emerged as pragmatic practitioners understanding that infrastructure constraints, diverse learner needs, and fundamental pedagogical principles shaped learning more profoundly than device availability. This transformation aligns with Pettersson's (2021) research demonstrating that authentic field experience in resource constrained contexts develops pedagogical problem-solving and creative adaptability characterizing expert teachers.

The universal reporting of infrastructure limitations (100% of participants) provides evidence regarding persistent educational inequity in the Indonesian context, consistent with broader documentation of urban-rural digital divides (Saborío Taylor & Rojas-Ramírez, 2024). Yet this universality paradoxically became a source of resilience. Participants confronting similar constraints developed shared adaptive strategies and collective understanding that effective teaching transcends technological access. One participant articulated this insight: "I learned that excellent teachers aren't those who always rely on technology, but those who create engaging, meaningful learning even when resources are limited." This perspective reflects what Ottenbreit-Leftwich et al. (2018) distinguish as overcoming first-order barriers (external constraints like technology access) through development of productive second order orientations (internal beliefs about learning emphasizing pedagogical over technological priorities).

Supporting factors operated through distinct mechanisms. Faculty modeling provided embodied examples of competency integration participants learned not from abstract description but from observing expert practitioners enacting integrated practice. This finding corroborates Rönnerman et al. (2021) research demonstrating that faculty modeling of integrated approaches to teaching content, pedagogy, and digital tools produces pre-service teachers better prepared for contemporary challenges. Intrinsic motivation anchored persistence through obstacles;

motivation centered on student learning impact proved more durable than external incentives like grades or career advancement. This aligns with self-determination theory applied to teaching contexts (Deci & Ryan, 2020), which identifies purpose as a fundamental psychological need. Participants demonstrated clear purpose orientation desire to create meaningful learning and witness positive impact on students that sustained effort despite challenges.

#### *Emergent Conceptual Frameworks*

Three interconnected conceptual frameworks emerged from integrating quantitative patterns with qualitative insights, proposing theoretical perspectives warranting further investigation across diverse contexts:

Synergistic Competency Framework proposes that PCK and instructional design skills generate multiplicative rather than merely additive effects. The framework posits that PCK without design capacity remains underutilized theoretical knowledge, while design skill without PCK produces technically proficient but pedagogically misaligned instruction. This perspective challenges conventional teacher knowledge literature treating competencies as independent additive components. The assertion receives support from recent scholarship: Carlson et al. (2019) demonstrated that PCK is dynamically constructed through practice and reflection cycles requiring structured design capabilities, while Dick et al. (2015) positioned instructional design as systematic translation of learning principles into instructional plans a process our findings suggest requires PCK as its foundation. Further research examining how PCK-design synergies develop across teacher career stages and subject domains would advance understanding of optimal preparation approaches.

Grade Responsive Pedagogy Framework asserts that elementary teaching requires fundamentally different competency deployment than other educational levels due to young learners' developmental characteristics. Participants consistently recognized that elementary learners in Piaget's concrete operational stage require specific pedagogical approaches concrete materials, integrated content, connections to daily life experiences distinct from abstract instruction appropriate for older students. This awareness aligns with foundational cognitive development research (Piaget, 1970) and recent applications demonstrating that Piagetian constructivist principles remain relevant when teachers attend carefully to developmental stages (Helmi et al., 2024). One participant articulated this understanding: "*Elementary children are still developing physically, socially, emotionally, and cognitively, so they need concrete, experiential learning.*" This framework challenges generic teacher preparation models applying

uniform pedagogical approaches across grade levels, suggesting instead that preparation must be grade-responsive. Wiggins et al. (2024) recent work acknowledges that while backward design principles apply universally, implementation must adapt to developmental contexts, particularly in elementary settings where concrete experience remains pedagogically foundational.

Pedagogy Primacy Framework contends that pedagogical competence constitutes teaching's non-negotiable foundation, with technology as strategically important but fundamentally secondary. This framework emerges inductively from converging evidence: participants with strong pedagogy created impactful learning despite infrastructure limitations, while participants with technology access but weaker pedagogy produced superficial engagement. The framework directly counters educational technology discourse positioning technology as foundational to 21st-century teaching. Merrill (2024) articulated a related position: instructional design effectiveness depends primarily on pedagogical principles' quality, not technology sophistication employed. Our findings demonstrate this principle empirically in elementary contexts. When participants reported effective technology use, they consistently framed it within pedagogical purposes: "*I use animations to visualize processes difficult to observe directly*" or "*I use interactive quizzes because immediate feedback supports learning.*" Conversely, technology implementation failures typically resulted from pedagogical misalignment: "*The technology distracted from the actual learning objective*" or "*Students focused on screens rather than understanding concepts.*" This pattern aligns with Reiser et al. (2024) assertion that strong pedagogy with limited technology outperforms weak pedagogy with extensive technology. Testing this framework across diverse technological contexts would clarify boundary conditions and contextual moderators.

#### *Integrated Model: Subject-Specific Deep Learning Pedagogy (SSDLP)*

The SSDLP model synthesizes these three frameworks, proposing that impactful elementary learning requires simultaneous attention to subject matter specificity (what is taught), pedagogical depth beyond rote memorization (how it is taught), and systematic design implementation (structured planning and sequencing).

The model positions PCK and instructional design skills as core competencies mutually reinforcing through iterative cycles of planning, implementation, reflection, and refinement a process reflecting Schmid et al. (2021) concept of the reflective practitioner validated in contemporary research (Sitompul et al., 2025).

Participants demonstrated such reflection: "I always reflect after teaching to identify what worked, what didn't, and how to improve." Digital literacy enters the model as strategic support, selected and applied specifically to enhance pedagogically sound practices rather than driving instructional decisions. Supporting factors, inhibiting factors, and moderating factors identified in qualitative analysis function as contextual influences shaping how core competencies develop and interact.

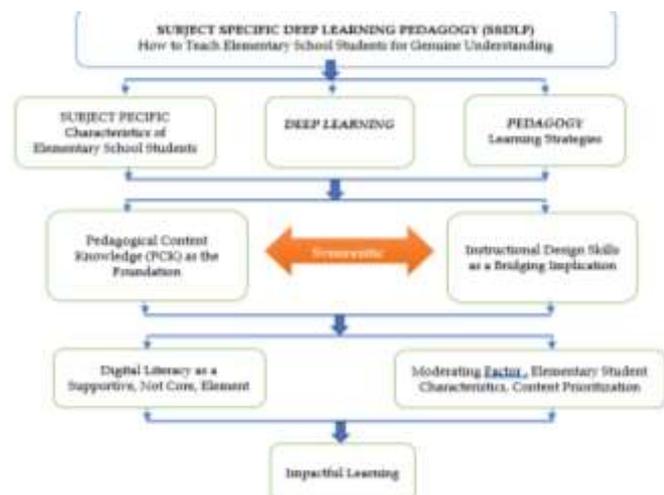


Figure 3. Frameworks SSDLP

Practical Implications for Teacher Education

These findings suggest that elementary teacher preparation programs should consider several design principles (Sari et al., 2023). First, programs should prioritize integrated development of PCK and instructional design skills through coherent curricula where content courses explicitly address teaching specific content to elementary learners, avoiding isolated competency development. As recent research confirms, PCK development requires integration of content and pedagogical knowledge in practice-focused contexts (Carlson et al., 2019). Second, digital literacy should be positioned not as separate competency but as strategic resource deployed within pedagogically sound design, with technology introduced to serve identified pedagogical purposes rather than as isolated skill (Schmid et al., 2021). Third, programs should substantially extend field-based learning, allowing students to confront infrastructure realities and develop adaptive expertise through authentic practice (Pettersson, 2021). Fourth, programs should deliberately cultivate moderating factors identified analytical approaches emphasizing pedagogical priority, developmental appropriateness, and creative problem-solving within constraints through explicit instruction in balanced learning approaches and technology effectiveness evaluation.

Limitations and Future Research Directions

This study examined students from a single institution, potentially limiting generalizability. Replication across diverse institutional contexts (public universities, private institutions, regional variations) would strengthen claims about findings' transferability. Additionally, the study measured student perceptions during pre-service preparation; longitudinal research following graduates into practice would clarify whether these competency patterns predict actual classroom effectiveness. Future research might productively investigate competency development variation across content areas, as this study did not examine subject-specific patterns (Nurmasyitah et al., 2022). The ecosystem factors identified suggest systems-level interventions beyond individual preparation infrastructure investment, administrative support, cultural shifts valuing pedagogy over technology that would likely amplify improvements identified here. Research examining these broader system factors would complement individual level findings. Finally, investigating how professional learning communities focused on collaborative inquiry support ongoing competency integration across the transition to school-based teaching would address the reality that competency development represents an ongoing professional journey rather than a destination reached during pre-service preparation.

Conclusion

This research investigated the synergistic relationships among Pedagogical Content Knowledge (PCK), digital literacy, and instructional design skills in creating impactful learning among elementary teacher education students in Indonesia. Through mixed-methods sequential explanatory analysis integrating quantitative structural equation modeling of 220 respondents with qualitative thematic analysis of 15 focus group participants, the study reveals that impactful learning emerges from integrated competencies rather than isolated skills. Statistical analysis confirmed that PCK and instructional design skills are the dominant predictors ( $p < 0.001$ ), with their combined influence explaining 70% of the variance in impactful learning. While digital literacy demonstrated statistical significance ( $p = 0.002$ ), its relative contribution was substantially smaller than pedagogical competencies, indicating that technology's educational impact depends fundamentally on pedagogical grounding. Rather than functioning as independent, additive competencies, PCK and instructional design demonstrated complementary relationships where each amplifies the other's effectiveness. This synergistic integration challenges conventional assumptions positioning technology as foundational to contemporary

teaching and instead emphasizes that pedagogy remains primary, with technology serving as a strategic tool within coherent pedagogical frameworks. The qualitative findings consistently highlighted that field experience, intrinsic motivation focused on student learning impact, and faculty modeling functioned as critical supporting factors, while infrastructure limitations, technology access constraints, and time pressures emerged as inhibiting factors. Notably, pre-service teachers with strong pedagogical foundations developed adaptive strategies enabling effective teaching even under resource constraints. Three Proposed Theoretical Frameworks emerged from this research: (1) a Synergistic Competency Framework proposing that PCK and instructional design generate multiplicative rather than additive effects; (2) a Grade-Responsive Pedagogy Framework asserting that elementary teaching requires pedagogical approaches distinct from other educational levels; and (3) a Pedagogy Primacy Framework contending that pedagogical competence constitutes teaching's foundational requirement with technology as secondary support. These frameworks synthesize within the Subject-Specific Deep Learning Pedagogy (SSDLP) model, which integrates subject matter specificity, pedagogical depth, and systematic design implementation as essential components: Impactful Learning =  $f(\text{PCK, Instructional Design Skills, Digital Literacy, Context})$ . The research demonstrates that teacher preparation programs aligned with these findings prioritizing integrated PCK and instructional design development, positioning digital literacy as pedagogically grounded support, cultivating moderating factors emphasizing pedagogical priority and adaptive problem solving, and providing extended authentic field experience are more likely to prepare elementary educators capable of creating meaningful learning across diverse, often resource-constrained contexts. For policy and practice, findings suggest that investment in pedagogical competency development may prove more cost-effective for educational improvement in resource-limited contexts than technology infrastructure expansion, particularly when combined with preparation emphasizing adaptive expertise. Future research should examine whether these competency integration patterns transfer across diverse institutional contexts, subject areas, and whether pre-service competency development predicts in-service classroom effectiveness through longitudinal follow-up studies.

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#### Author Contributions

Conceptualization, S., Y., and D.; methodology, software, validation, S., Y., and D.; formal analysis, investigation, data curation, writing—original draft preparation, writing—review and editing, S., Y., and D.; visualization, supervision, S., Y., and D.; project administration, funding acquisition, and S. All authors have read and agreed to the published version of the manuscript.

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#### Conflicts of Interest

The authors declare no conflict of interest.

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