Determination of the Effectiveness of Digital-Based PPG: A Systematic Literature Review of Pedagogical Contributions, Learning Materials, and Infrastructure through Quality Learning Processes

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Abstract
The digitalization of the Teacher Professional Education (PPG) Program requires pedagogical readiness, quality learning materials, and infrastructure support to maintain program effectiveness. However, empirical evidence related to the determinants of the effectiveness of digital-based PPG is still scattered and has not been systematically synthesized, particularly regarding the role of quality learning processes as a link between variables. This article aims to examine the determinants of the effectiveness of digital-based PPG through a systematic literature review (SLR) with a focus on the contribution of pedagogical competence, learning materials, and infrastructure through a quality learning process. The SLR was conducted following the PRISMA stages: formulation of research questions, literature searches in academic databases/search engines, study selection with inclusion-exclusion criteria, article quality assessment, and thematic synthesis. The results of the study show three main findings. First, pedagogical competence (especially digital pedagogy) influences effectiveness through active learning design, facilitation of interaction, provision of formative feedback, and management of online assessments. Second, the quality of learning materials determines engagement and understanding through the appropriateness of outcomes, clarity of structure, interactivity, and integration of assignments and assessments. Third, infrastructure (device access, connectivity, LMS, and technical support) is a prerequisite for sustainable learning and moderates process outcomes. Consistently, these three factors have the strongest impact when realized in a quality learning process that is collaborative, reflective, and data-driven. The study's implications emphasize strengthening digital pedagogical capacity, standardizing content quality, and investing in infrastructure and supporting services for the sustainable effectiveness of digital PPG.

Keywords: Digital-based PPG, Program effectiveness, Pedagogical competence, Learning materials, Infrastructure, Quality of the learning process

Introduction

Digital transformation has transformed the way teacher education is designed, delivered, and evaluated. This shift extends beyond platform use to pedagogical practices in the classroom. As learning shifts to online environments, the quality of interactions and instructional design become key determinants of learning outcomes. Global reports emphasize that technology can improve access, but it can also widen inequalities if governance and preparedness are inadequate (UNESCO, 2023). Therefore, the effectiveness of digital-based teacher professional programs needs to be viewed as a matter of quality, not simply the availability of applications. Assuring the quality of digital learning requires indicators that assess processes, learning experiences, and competency outcomes. In many countries, teacher quality improvement agendas prioritize digital literacy as a prerequisite for 21st-century professionalism. However, digital literacy without appropriate pedagogy risks producing “merely online” learning without depth. Therefore, research examining the

determinants of the effectiveness of digital-based teacher professional programs is scientifically and policy-relevant.

In the Indonesian context, the Teacher Professional Education Program for in-service teachers is a crucial pathway to certification and competency development. National regulations outline the implementation framework, requirements, and procedures for obtaining teacher certification for in-service teachers (Ministry of Education, Culture, Research, and Technology, 2022). Consequently, the quality of PPG implementation directly impacts the quality of educational services in schools. The shift in PPG service patterns toward a digital ecosystem demands new standards in planning, implementation, and evaluation. Online classes shift the center of learning control from physical spaces to learning management systems that rely on design and support. At the same time, teachers, as learners, bring diverse contexts, experiences, and uneven access. These inequalities have the potential to impact the learning process, motivation, and successful completion of the program. Therefore, the effectiveness of digital-based PPG needs to be comprehensively understood, encompassing pedagogical factors, materials, and infrastructure. A comprehensive approach is crucial to prevent recommendations from becoming fixated on a single solution.

The effectiveness of digital-based programs is also influenced by the reach of distance learning at the participant level. A study on learning affordability during school closures introduced indicators that emphasize the dimension of equity in access. The affordability indicators confirm that access to devices, electricity, and connectivity determines who can continue learning. These findings reinforce the argument that infrastructure is not a background factor, but rather a key variable. When infrastructure is weak, even the best instructional designs struggle to perform consistently. In teacher training, connectivity disruptions can hinder synchronous participation and reduce the quality of feedback. Unstable access also triggers pragmatic learning strategies, such as rushing through assignments without reflection. Therefore, infrastructure in digital PPG must be treated as a determinant of process quality. An equity perspective helps explain why program impacts may differ across regions and groups. Analysis of the determinants of effectiveness needs to incorporate access issues to ensure equitable and applicable recommendations.

Pedagogy is at the heart of quality learning, including in digital ecosystems. In online spaces, pedagogy plays a role in orchestrating objectives, activities, interactions, and assessments in an integrated manner. The Community of Inquiry framework emphasizes the importance of "teaching presence" as a driver of meaningful learning experiences. Meta-analyses show that teaching presence is strongly correlated with perceived learning outcomes and learning satisfaction. These findings confirm that the role of the facilitator is not lost in digital learning, but rather transformed. PPG tutors or lecturers need to provide clear structure, responsive guidance, and strengthen the learning community. When pedagogical structure and support are weak, participants are prone to digital fatigue and task confusion. Quality learning requires consistent discussion management, practice modeling, and formative assessment. Therefore, the contribution of pedagogy to the effectiveness of digital PPG deserves to be examined as a key factor. Pedagogy also interacts with the quality of materials and infrastructure readiness, so its analysis should not be partial. (Caskurlu, 2020)

Beyond pedagogy, the quality of learning materials determines the depth of the learning process. Digital materials cannot simply be transferred from printed modules to PDF, as learners' cognitive needs differ on screen. Quality materials require conceptual structure, authentic examples, and activities that encourage elaboration. Materials must also support the application of teachers' professional competencies, not just theoretical understanding. In PPG, materials should connect learning theory, lesson planning, and reflective practice. When materials are not contextualized, learners tend to copy answers or simply fulfill rubrics. Good

materials facilitate problem-based learning and real-life classroom case studies. Materials integrated with formative assessments also make it easier for learners to monitor progress. Thus, learning materials become a determinant that works through the quality of the learning process, such as engagement and reflection. A literature analysis needs to map the indicators of material quality that most consistently contribute to program effectiveness. (Bragg, 2021)

The infrastructure in digital PPG includes devices, networks, platforms, and technical support. In practice, the platform becomes a classroom that integrates content, interaction, and assessment. UNICEF emphasizes the importance of strengthening digital content, developing digital skills, and expanding school connectivity. These recommendations align with the needs of teacher professional programs, which demand consistent access. Without infrastructure support, quality learning processes are difficult to sustain. Technical barriers also reduce cognitive focus because participants' energy is drained on operational issues. Good infrastructure is not just "there," but also easy to use, stable, and supports interaction. Responsive technical support helps prevent a decline in motivation when problems occur. In program evaluation, infrastructure should be measured as a user experience, not just inventory. Therefore, this study positions infrastructure as a determinant that influences effectiveness through the quality of the learning process.

The quality of a quality learning process can be understood as a connecting mechanism between program inputs and effectiveness. A quality process is characterized by clear objectives, meaningful activities, productive interactions, and assessments that drive improvement. Within the Community of Inquiry framework, a quality process is realized through a balance of teaching presence, social presence, and cognitive presence. Meta-analysis shows that presence in a Community of Inquiry (CoI) is related to satisfaction, perceived learning, and learning outcomes. This finding strengthens the position of "process" as a plausible mediation pathway for assessing the effectiveness of digital programs. If pedagogy, materials, and infrastructure are strong, presence is more easily achieved consistently. Conversely, if any of the inputs are weak, presence can be skewed and degrade the learning experience. Thus, a conceptual model that incorporates a quality learning process as a mediator has a strong theoretical basis. In digital PPG, a quality process also includes practical guidance, reflection, and structured feedback. Therefore, a systematic review is needed to explore how research models quality processes in the context of teacher training. (Martin, 2022)

Learning analytics is increasingly important for monitoring and improving the quality of digital learning processes. In LMS-based programs, activity log data can reveal engagement patterns and the risk of dropout. A systematic review shows that learning analytics can enrich feedback practices for educators and learners. These findings emphasize that data does not automatically improve quality but must be translated into relevant interventions. In the context of PPG, analytics can help personalize support, for example, for learners who are falling behind. However, the application of analytics requires consideration of the ethics, privacy, and fairness of data use. When used appropriately, analytics can strengthen formative assessment and learner reflection. This aligns with the concept of a "quality learning process" that emphasizes continuous feedback. Therefore, determining the effectiveness of digital PPG needs to also examine the system's capacity to provide information on learning progress. A literature review can map process indicators most frequently measured through analytics, such as access duration, task completion, and discussion engagement.

The digital competence of teachers as PPG participants influences how they utilize materials and platforms. A systematic review shows that digital competence relates to the ability to select resources, manage activities, and conduct technology-based assessments. At the individual level, digital competence influences self-efficacy and independent learning strategies. At the process level, digital competence influences the quality

of discussions, collaboration, and the accuracy of assignment submissions. Therefore, the literature on digital competence is relevant for understanding variations in digital PPG outcomes. However, digital competence is also shaped by the learning experiences within the program itself. This means that digital PPG can serve both as pedagogical training and as a reinforcement of digital competence. Within this framework, program pedagogy needs to provide scaffolding to prevent participants from being left behind due to technical barriers. Materials should also be designed to be user-friendly, with clear instructions and followable examples. Stable infrastructure helps digital competence develop through repeated practice. Therefore, this literature review will examine how studies link digital competence to quality learning processes and effectiveness. (Smestad, 2023)

Online learning community practices are a crucial element in digital-based teacher training. A systematic review of online teacher communities shows that collaboration and shared practices can enhance professionalism. Communities also help teachers gain meaning from material through collective experiences and shared reflection. In digital PPG, discussion forums and collaborative spaces can serve as vehicles for professional identity formation. However, online communities require facilitation to ensure discussions are not superficial and dominated by a handful of participants. A strong teaching presence helps direct discussions toward competency goals. Authentic materials stimulate conversations based on real cases, not just opinions. Good infrastructure ensures participation is not hampered by access constraints. Thus, online learning communities function as part of a quality learning process that bridges input and effectiveness. The literature also shows that community sustainability is influenced by a culture of sharing and trust among members. Therefore, this study views community interaction as an indicator of a quality process in digital PPG.

Policy developments require PPG implementation to be increasingly adaptive to technology. The technical guidelines for implementing in-service PPG indicate an operational framework that organizers must adhere to. This framework impacts learning design, mentoring, and assessment in the LMS. As the program transitions to a digital format, procedural standardization needs to be balanced with pedagogical flexibility. If procedures are too administrative, participants risk focusing on document completeness rather than competency. If procedures are too lax, assessment quality can be inconsistent across organizers. Therefore, determinants of effectiveness must consider how policies translate into learning practices. Good pedagogy can be a mechanism for maintaining quality within the procedural framework. Learning materials must also be aligned with competency outcomes stipulated by regulations. Infrastructure and technical support need to be ensured to ensure implementation adheres to schedules and service standards. Therefore, the literature review will examine the relationship between policy compliance, process quality, and program effectiveness.

At the implementation level, user acceptance of an LMS is a crucial issue in digital PPG. A Technology Acceptance Model-based study shows that perceived usefulness and ease of use influence LMS acceptance by PPG participants. When participants perceive a platform as simplifying tasks, they engage more consistently in learning activities. Conversely, when the platform is perceived as complicated, participants tend to avoid collaboration features and focus solely on submitting assignments. This technology acceptance is directly related to the quality of the process, as engagement is a prerequisite for discussion and reflection. Therefore, infrastructure should be assessed based on user experience, not just technical features. Pedagogy should also consider user orientation through initial training and step-by-step guides. Good materials can be designed modularly to avoid overwhelming participants in navigation. Ultimately, program effectiveness is determined by the combination of platform acceptance and the quality of instructional design. The literature addressing LMS acceptance in PPG helps highlight the mediating pathways through which quality learning occurs.

Empirical evidence on LMS-based PPG shows variations in learning experiences across universities and participants. Some studies highlight that LMSs can improve learning regularity if activities and schedules are clear. Others emphasize that meaningful interactions require active facilitation from lecturers and mentors. These findings reinforce the position of pedagogy as a driving factor in the digital space. When mentors are consistently present, participants more easily understand expectations and improve performance. However, when mentoring is minimal, participants tend to rely on peers or seek information outside the system. This can lead to heterogeneity in understanding and assignment quality. Rubric-guided learning materials can clearly reduce heterogeneity, but still require good examples. Stable infrastructure strengthens the continuity of mentoring and prompt responses to questions. Therefore, a systematic review needs to map the implementation factors that most frequently emerge as explanations for the effectiveness of digital PPG. This mapping is crucial for formulating evidence-based recommendations across contexts (Bashori, 2024).

A quality learning process is also related to assessment and feedback that drive improvement. In teacher training, feedback is not just about grades, but also guidance for improving teaching practice. Learning analytics can help provide more timely and specific feedback. However, assessment design must still measure pedagogical, professional, social, and personality competencies in line with program objectives. Learning materials should provide examples of teaching tools, practice videos, and reflections that can be tested through authentic assignments. Good pedagogy integrates formative assessments throughout each module, rather than piling them up at the end. Infrastructure should also support video uploads, reflective discussions, and rubric assessments. When features are inadequate, authentic assessments often degenerate into simple quizzes that underrepresent competencies. Therefore, the effectiveness of digital PPG must be measured by the extent to which assessments support learning, not simply by auditing completion. The literature review will assess how studies operationalize "effectiveness" as a composite of learning outcomes, satisfaction, completion, and changes in practice (Pan, 2024).

The issue of the digital divide in Indonesia provides important context for digital-based PPG. UNICEF emphasized bottlenecks in access, devices, and skills that impact digital learning. The World Bank also reviewed the online teacher training ecosystem in Indonesia and highlighted challenges to quality and effectiveness. These findings suggest improvements in program design, content quality, and support mechanisms are needed. Similar challenges can arise in PPG, as participants come from regions with varying digital readiness. If disparities are not considered, digitalization policies can benefit certain groups and disadvantage others. Therefore, infrastructure needs to be mapped as a minimum prerequisite for program participation. Pedagogy should also implement differentiated support for participants with low digital competency. Learning materials need to be designed to adapt to bandwidth limitations, for example by providing lightweight versions and limited offline access. Quality learning processes need to incorporate inclusive strategies, such as flexible schedules and alternative assignments. With this context, a systematic review can produce more realistic and equitable recommendations for improving digital PPG.

The literature on online teacher professional development indicates that the quality of program design is crucial for impact. Systematic reviews emphasize the importance of content coherence, collaboration, facilitator support, and practical application. Effective programs typically combine theory and practice through authentic assignments and reflection. They also emphasize ongoing support, rather than one-way training. In digital PPG, this coherence needs to be maintained to prevent modules from becoming fragmented across presenters. Pedagogy must ensure that the learning flow reinforces competency achievement gradually. Learning materials must bridge real-world classroom contexts with professional demands. Infrastructure must

support collaboration and the digital presentation of evidence of teaching practice. A quality learning process is the intersection of all these elements. Thus, pedagogical variables, materials, and infrastructure are reasonably positioned as determinants that operate through a quality process (Bragg, 2021).

To rigorously map the evidence and ensure clear replication, this study employed a systematic literature review approach. PRISMA 2020 provides reporting guidelines that enhance transparency in the process of identifying, selecting, and synthesizing studies. In the educational context, a systematic literature review (SLR) helps mitigate selection bias because inclusion and exclusion procedures are explicitly stated. It also allows researchers to assess the consistency of findings across contexts and study designs. The SLR methodology requires a systematic search strategy, criteria-based filtering, and structured data extraction. In this study, a systematic literature review (SLR) was chosen because the topic of digital PPG encompasses multiple domains, such as pedagogy, technology, materials, and infrastructure. A traditional narrative approach risks missing key studies and confounding the quality of evidence. With a systematic literature review (SLR), the relationships between determinants and process mechanisms can be mapped in a clearer pattern. SLRs are also relevant for proceedings because they can produce “evidence maps” that are useful for policymakers. Therefore, the PRISMA framework will serve as a primary reference for maintaining the traceability and credibility of the synthesis.

In the methodology literature, SLR is understood as a strategy for systematically building cumulative knowledge. SLR guidelines emphasize the importance of formulating specific and operationalized research questions. The literature also emphasizes the need to assess study quality to ensure that the synthesis does not equate weak and strong evidence. In education studies, SLR is often used to map learning interventions and the factors that influence outcomes. SLR is also useful for identifying research gaps, such as variables that are frequently mentioned but rarely measured. For the topic of digital PPG, a common gap is the separation of input factors without assessing process mechanisms. Therefore, this study focuses on the quality learning process as a pathway that explains the contribution of determinants. Conceptually, this approach aligns with the input-process-output logic in program evaluation. Thus, the synthesis will group findings based on relationships between variables, rather than simply listing factors. Ultimately, SLR results are expected to produce a determinant framework that can be tested in subsequent empirical research (Snyder, 2019).

This research's conceptual framework positions the effectiveness of digital PPG as a multidimensional outcome. Effectiveness can encompass competency achievement, UKMPPG graduation, participant satisfaction, and indications of practice changes. Pedagogical variables include instructional design, facilitation, formative assessment, and feedback quality. Learning material variables include structural clarity, relevance, authenticity of tasks, and theory-practice integration. Infrastructure variables include device access, connection stability, platform features, and technical support. Quality learning processes include engagement, collaborative interactions, presence in the CoI, and feedback-based reflection. Theoretically, strong input enhances quality processes, which then drive better outcomes. The CoI and learning analytics literature provide a basis for modeling processes as mediators. With this framework, recommendations can be directed at the most influential "levers" for program improvement. Furthermore, this framework allows for mapping operational indicators that can be adopted by organizers. Thus, this research contributes to the integration of cross-study findings into a more coherent determination model (Carroll, 2025).

Practically, the results of the systematic review are expected to help PPG providers improve the quality of digital learning services. Pedagogical findings can be translated into facilitation guidelines, feedback standards, and collaborative activity designs. Material findings can be used to strengthen the quality of modules, videos,

teaching tool examples, and authentic assignments. Infrastructure findings can inform investment priorities, technical support, and user-friendly platform design. Findings on quality processes can serve as more meaningful monitoring indicators than mere completion rates. For policymakers, evidence synthesis can aid in the development of more evidence-based digital PPG quality standards. For researchers, evidence maps can highlight variables that have not been consistently measured and opportunities for further research. Furthermore, this review can identify vulnerable contexts, such as areas with low access and the need for differentiated support. Thus, the research contribution goes beyond study summaries to include implementable recommendations. The following article outlines the SLR method, the results of the thematic synthesis, a discussion of the determination model, and implications for strengthening digital-based PPG.

Methodology

This study employed a Systematic Literature Review (SLR) design to synthesize empirical and conceptual evidence on the determinants of the effectiveness of digital-based PPG. SLR was chosen because it minimizes selection bias through transparent and replicable search, screening, and synthesis procedures (Snyder, 2019). SLR reporting follows PRISMA 2020 guidelines to clearly trace the study identification, selection, and inclusion process (Page et al., 2021). A working protocol was developed from the outset, encompassing the research question, search strategy, inclusion and exclusion criteria, quality assessment procedures, and synthesis techniques. This approach is relevant because digital PPG studies span a variety of study designs (surveys, program evaluations, policy studies, and tool development). Furthermore, SLR allows for systematic mapping of relationships between constructs, particularly the mediating role of quality learning processes. Thus, this methodology leads to a more coherent evidence map and conceptual model (Xiao & Watson, 2019).

Research questions were formulated to guide the search strategy and coding of findings. The primary question was: how do pedagogy, learning materials, and infrastructure contribute to the effectiveness of digital-based PPG through quality learning processes? Derivative questions included: (a) which digital pedagogical indicators are most consistently related to the quality of the learning process; (b) which characteristics of learning materials are most frequently reported to support engagement and outcomes; (c) which infrastructure components are most dominantly prerequisites or barriers; and (d) how effectiveness is defined/measured in digital PPG studies (e.g., satisfaction, competency achievement, graduation, or changes in practice). The questions were formulated based on the principles of measurability and traceability to align with SLR procedures (Xiao & Watson, 2019). The input–process–output conceptual framework was used to maintain consistency in the analysis. Input includes pedagogy, materials, and infrastructure; process is the quality of the learning process; and output is the effectiveness of the program. This framework helps avoid generalizations that only highlight the platform without assessing the process mechanisms.

Literature searches were conducted in databases and academic search engines relevant to education and learning technology, such as Scopus, ERIC, Google Scholar, and national indexes (e.g., Garuda/SINTA) to cover the Indonesian context. Source selection aimed to capture international and national literature discussing PPG, teacher professional education, and similar digital-based programs. The search strategy used a combination of keywords and Boolean operators (AND/OR) as well as variations of synonyms for each construct. Examples of search strings (adjusted per database) are: (“Teacher Professional Education” OR PPG OR “teacher professional education”) AND (digital OR online OR “e-learning” OR LMS OR “learning management system”) AND (pedagog* OR “teaching competence” OR “instructional”) AND (“learning material” OR module OR content) AND (infrastructure OR facilities OR ICT) AND (“learning process quality”

OR "quality learning" OR engagement) AND (effectiveness OR outcomes). Truncation (e.g., pedagog*) was used to capture variations of the term. The search also utilized backward-forward searching techniques through bibliographies of key studies and relevant citations to increase coverage (Snyder, 2019). The entire search process was documented: search date, database, final string, and number of initial results according to the PRISMA principle (Page et al., 2021).

Inclusion criteria were established to ensure that the selected studies aligned with the research objectives and the requested timeframe. Studies were included if: (1) they were published within the last 8 years (2018–2025); (2) they discussed digital-based PPG in Indonesia or equivalent digital-based professional education/teacher training programs; (3) they contained evidence related to at least one determinant (pedagogic, materials, infrastructure) and/or quality learning process; (4) they presented extractable empirical findings (quantitative, qualitative, mixed-method) or program evaluations; and (5) their full text was available. Studies were excluded if: (1) they were not related to the context of professional education/teacher training; (2) they were merely popular opinions without methods; (3) they did not substantively mention digital aspects (merely as labels); (4) they contained duplicate publications; or (5) their data/findings could not be extracted for synthesis purposes. Accepted publication languages included Indonesian and English to broaden the scope of evidence. These criteria balance stringency (to ensure relevance) and flexibility (to ensure evidence is not overlooked), as recommended in the SLR (Xiao & Watson, 2019). All criteria were applied consistently throughout the screening and final inclusion stages.

Study selection followed the PRISMA steps: identification, title-abstract screening, full-text eligibility assessment, and final inclusion (Page et al., 2021). During the identification stage, all search results were exported to a reference management tool to eliminate duplication. The title-abstract screening stage was conducted based on predetermined inclusion-exclusion criteria. Studies that passed the screening stage proceeded to the full-text reading stage to ensure appropriateness for context and variables. Reasons for exclusion at the full-text stage were recorded (e.g., irrelevant, missing target variable, or unavailable extractable data). To enhance reliability, the selection process was conducted by two reviewers independently, and disagreements were resolved through criteria-based discussions. When necessary, a third reviewer acted as arbitrator. The final selection results are presented in a PRISMA diagram along with a summary of the number of studies at each stage (Page et al., 2021).

Quality assessment was conducted to ensure the synthesis did not equate lower-quality evidence with stronger evidence. Because the educational literature is often heterogeneous, assessment instruments compatible with different designs were considered. This study employed critical appraisal principles to assess: clarity of purpose, appropriateness of design to the research question, sample/participant quality, instrument validity, analytical procedures, transparency of reporting, and data support for conclusions. For mixed-method studies, a common assessment framework can be based on the latest version of the Mixed Methods Appraisal Tool, widely used in educational syntheses (Hong et al., 2018). Quality scores or categories (e.g., high–moderate–low) were used to base weighted interpretations of findings, rather than to automatically exclude them, unless studies were particularly weak and at risk of misrepresentation. The results of the quality assessment were recorded on the extraction sheet and reported concisely in the results section. This approach aligns with the SLR principle, which emphasizes transparency and careful inference (Snyder, 2019). Thus, dominant findings from low-quality studies will be clearly noted for limitations.

Data extraction was conducted using a data extraction form developed prior to the full review to ensure consistency. Information extracted included: author–year, program location/context, study objectives,

design/methods, participant characteristics, platform/technology used, definitions and indicators of effectiveness, and key findings related to pedagogy, materials, infrastructure, and quality learning processes. For the purposes of the conceptual model, each finding was coded based on the following categories: (a) Pedagogy (e.g., activity design, interaction facilitation, formative feedback, assessment); (b) Materials (content structure, interactivity, task authenticity, assessment integration); (c) Infrastructure (device access, connectivity, LMS features, technical support); (d) Process (engagement, collaboration, reflection, clarity of flow, quality of feedback); and (e) Effectiveness (satisfaction, competency attainment, graduation, changes in practice). Coding was iterative; initial codes could be expanded into sub-codes if the literature revealed specific recurring themes. To enhance precision, operational definitions for each code were written explicitly and used consistently. This procedure follows SLR practices that demand category transparency and extraction consistency (Xiao & Watson, 2019).

The synthesis was conducted using a thematic narrative approach because the heterogeneity of designs and effectiveness indicators in the digital PPG literature typically complicates quantitative meta-analysis. Thematic synthesis combined findings across studies to identify patterns of determinant contributions and process mechanisms. First, findings were grouped by determinant (pedagogy, materials, infrastructure) and their impact on process indicators was recorded. Second, findings were integrated to assess the consistency of the relationship between determinants and quality processes and effectiveness. Third, evidence was mapped onto a conceptual mediation framework to identify dominant and under-tested pathways. Fourth, where the literature permits, comparisons were made based on context (Javanese vs. Pre-service PPG, field of study, or platform variations). The synthesis results are presented as main themes and subthemes, accompanied by a summary of supporting evidence for each theme. This strategy aligns with the SLR's goal of building a unified understanding and identifying research gaps (Snyder, 2019). All conclusions are presented taking into account the quality of the studies and the limitations of the context.

To ensure validity, the study implemented detailed documentation at each stage: search strategy, exclusion reasons, quality assessment, and coding rules. Study selection and coding were conducted by two independent reviewers to mitigate individual bias. Differences in decisions were resolved through criteria-based discussions, and records of revisions were kept. The risk of publication bias was mitigated by including relevant national sources and proceedings as long as they met the criteria and had full text available. Furthermore, the synthesis not only emphasized positive findings but also included evidence of constraints and contradictions to maintain a balanced interpretation. When inconsistencies in results were identified, the study explored possible causes, such as differences in context, quality of infrastructure, or differences in definitions of effectiveness. Transparency in reporting followed PRISMA to enable readers to assess the robustness of the procedures used (Page et al., 2021). With this strategy, the SLR results are expected to be credible and can be used as a reference for program improvement and further research.

This SLR uses secondary data from scientific publications and therefore does not involve direct interaction with participants. Therefore, participant consent is not required, but academic ethics are maintained through appropriate citation and honest reporting. Careful interpretation of results is conducted, avoiding causal claims unsupported by the study design. Furthermore, limitations of the evidence are explicitly stated in the discussion section to ensure that users of the study understand the scope of generalization. The principles of transparency, accountability, and replicability are the primary ethical foundations of the SLR (Snyder, 2019; Page et al., 2021). Thus, this methodology ensures scientific integrity as well as practical relevance for improving the quality of digital-based PPG.

Result And Discussion

The literature shows that the effectiveness of digital-based PPG is not simply a result of platform availability, but rather the interaction of many mutually reinforcing factors. Many studies position the quality of the learning process as the "engine" that transforms program inputs into competency outputs. Within this framework, digital pedagogy plays a role in regulating interaction strategies, assessment, and scaffolding. Learning materials serve as "content," which must be structured, contextual, and self-studyable. Infrastructure serves as a prerequisite, including connectivity, devices, and LMS reliability. When infrastructure is weak, cognitive load increases and learners' focus is distorted. When pedagogy is weak, interactions become shallow and competency objectives are not achieved. When materials are poor quality, learners tend to memorize without transferring them to practice. This layered pattern of relationships is consistent with a report on the online teacher training ecosystem in Indonesia, which emphasizes the quality of design and system support as determinants of outcomes (World Bank, 2022).

Conceptually, "effectiveness" in digital PPG literature is understood through output and outcome indicators. Outputs are often defined as the achievement of pedagogical-professional competencies, graduation rates, and performance in workshop or practical assignments. Outcomes are more often directed at changes in teaching practice, professional self-confidence, and readiness to implement differentiated learning. Several studies define effectiveness as participant satisfaction and perceived program usefulness. Although indicators vary, the consensus is that effectiveness increases when participants experience directed, interactive, and relevant learning. In a meta-analysis of CoI, teaching and social presence were positively associated with various learning outcomes in online environments. This finding confirms that the quality of the learning experience is a plausible mediator. Therefore, program input determinants should be assessed based on their contribution to process quality, not simply administrative completeness. This direction aligns with the conceptual distinction between designed online learning and "makeshift" practices that often degrade the quality of the learning experience (Hodges et al., 2020; Martin et al., 2022).

Pedagogy emerged as the most dominant theme in studies assessing digital-based professional programs. Digital pedagogy encompasses lesson planning, discussion management, instructional clarity, and feedback. Meta-analytic studies show that the "teaching presence" dimension has a moderate positive correlation with actual learning outcomes. This moderate correlation indicates that the quality of lecturer facilitation and learning structure have a significant impact. In the PPG context, pedagogy also includes coaching, mentoring, and strengthening evidence-based reflection. Indonesian literature indicates that support from lecturers, mentor teachers, and LMS administrators is part of the academic service experience that determines the quality of the process. When facilitation is consistent, participants are better able to complete complex assignments and integrate theory into the learning design. When facilitation is inconsistent, participants tend to focus on completing assignments rather than understanding meaning. This pattern reinforces the claim that pedagogy is a proximal determinant that drives participant engagement. This evidence aligns with findings that the success of online learning is highly sensitive to instructional design and teaching quality (Caskurlu et al., 2020; Sridadi et al., 2023).

The literature groups pedagogy into a clear and measurable subtheme of “learning design.” Good design displays complementary outcomes, activities, rubrics, and synchronous-asynchronous flows. In many contexts, unclear flows cause learners to expend energy guessing at task expectations. Design clarity also serves to control cognitive load on complex material. In multimedia learning, the structure and organization of information determine learners' ability to process, organize, and integrate knowledge. When the material

structure aligns with multimedia principles, conceptual understanding tends to improve. Conversely, digital materials that are text-heavy and lack visual explanations often lead to fatigue and decreased motivation. Thus, pedagogy directly intersects with material quality, as design determines how the material is presented. This finding aligns with multimedia learning principles that emphasize content organization, information selection, and meaningful integration (Mayer, 2021; Mayer & Fiorella, 2022).

The next pedagogical subtheme is "meaningful interactions," which go beyond administrative questions and answers. Meaningful interactions include conceptual dialogue, formative feedback, and collaboration on learning problem-solving. Within the CoI framework, meaningful interactions are reflected through teaching presence, social presence, and cognitive presence, which reinforce each other. A CoI meta-analysis shows that teaching presence is positively correlated with learning outcomes, including perceived learning and satisfaction. This finding can be interpreted as suggesting that lecturer facilitation is not an accessory, but rather a core component of online learning. In PPG, meaningful interactions are crucial because participants need to test their teaching tool designs and receive constructive criticism. Without strong interactions, participants may produce "neat" but inauthentic teaching tools in the classroom. Interactions also strengthen a sense of community, which reduces the risk of dropping out of digital-based programs. Thus, pedagogy serves as both a social bond and a cognitive guide. This evidence is consistent with the CoI literature, which positions presence as a predictor of online learning experiences and outcomes (Martin et al., 2022; Caskurlu et al., 2020).

The third pedagogical subtheme is "assessment and feedback" as a lever for process quality. Literature shows that prompt, specific, and rubric-based feedback enhances perceptions of fairness and clarifies quality standards. In the context of digital PPG, rubrics for teaching materials and practical assessments serve as important references for participants to understand the expected quality. When rubrics are not communicated, participants frequently request repeated clarification and reduce time for reflection. Formative feedback also accelerates improvements to learning designs before field practice. When feedback is only in the form of scores, participants lose diagnostic information for competency improvement. A study of fully online PPG services showed that the dimensions of "lecturers, mentor teachers, and LMS administrators" were assessed as service components that influence the learning experience. This indicates that feedback is not solely the responsibility of lecturers, but also of the facilitation ecosystem. At the policy level, the PPG implementation manual emphasizes process management and learning quality assurance as implementation guidelines. Therefore, assessment and feedback can be positioned as micro-mediators linking pedagogy to program effectiveness. This direction is in line with the idea that process quality is a prerequisite for valid competency output (Sridadi et al., 2023).

The theme of learning materials emerges as a determinant often underestimated because it is considered "just a module." The literature confirms that the quality of the materials determines cognitive depth and transfer to practice. Effective materials typically include authentic examples, case studies, and classroom scenarios relevant to the participants' context. Materials that simply present concepts without demonstrations are often insufficient to develop professional skills. In the context of digital PPG, modules should support self-directed learning through clear navigation and step-by-step tasks. Multimedia principles suggest that the presentation method influences information processing, not just the content. When materials combine text, visuals, and examples, participants more easily build mental models of learning. When materials are not self-directed, participants rely on synchronous explanations, thus decreasing program effectiveness. A study of PPG based on the LMS Space highlighted that a clear main menu made it easier for participants to follow the steps of the activities, and this was associated with a more focused learning experience. However, the same study also

confirmed that system errors and limited IT skills can hinder consistent access to the materials. Therefore, the quality of the materials is inseparable from the quality of the platform that delivers them. These findings are consistent with the principles of digital learning design and empirical evidence of PPG on LMS Space (Mayer, 2021; Firmansyah, 2022).

The literature maps learning materials into the subtheme of "relevance and contextuality." Relevance means that the material aligns with teachers' classroom tasks, not just fulfilling theoretical demands. Contextuality means that the material takes into account variations in schools, resources, and student characteristics. In PPG, context is crucial because participants come from diverse levels and regions. Reports on online teacher training in Indonesia emphasize the heterogeneity of teacher capacities and needs as a challenge to the quality of digital programs. Therefore, materials should provide learning pathway options or case differentiation. Material that allows for adaptation encourages participants to apply concepts to local situations. Conversely, material that is too generic makes it difficult for participants to translate concepts into teaching steps. This theme also relates to the PPG policy, which directs the strengthening of competencies in a standardized manner while remaining relevant to practice. In implementing the PPG policy, high administrative burdens and limited time can reduce opportunities for in-depth material learning. Therefore, concise, structured, and case-based materials are a strategy to maintain process quality under time constraints. This pattern aligns with recommendations for improving the quality of digital teacher training and aligning materials with practical needs (World Bank, 2022; Kurniawan, 2025).

The next subtheme of the material is "structure, sequencing, and readability." Structure refers to organizing objectives, key concepts, and tasks into a consistent learning flow. Sequencing means the material is structured from basic concepts to complex applications in a step-by-step manner. Readability means the language and presentation make it easy for participants to understand without the burden of excessive interpretation. Multimedia learning principles emphasize the importance of segmentation, tagging, and reducing irrelevant information. Segmentation helps participants process material in small chunks to avoid overwhelm. Tagging helps participants recognize important ideas and relationships between concepts. In digital PPG, good sequencing helps participants connect in-depth material, workshops, and field experience practices. If the sequence is illogical, participants construct learning materials without sufficient pedagogical foundation. If the sequence is too theoretical, participants lose momentum in application. Therefore, the structure of the material acts as a "rail" that keeps the quality learning process on track. These findings align with the multimedia design literature and the need for gradual professional learning (Mayer, 2021; Mayer & Fiorella, 2022).

The third material subtheme is "the quality of digital learning resources and academic integrity." Effective digital materials should include up-to-date references, examples of teaching tools, and demonstration videos of teaching practices. However, the literature also warns that widespread access to materials increases the risk of copy-pasting and plagiarism in assignments. Therefore, material design should encourage original thinking through contextual assignments and personal reflection. When assignments require adaptation to real-life classroom conditions, the opportunity for plagiarism decreases. Program policies and guidelines also typically emphasize authentic assessment to maintain the credibility of certification. In digital PPG, academic integrity is directly linked to the validity of program outcomes. If assignments are easily replicated, perceived effectiveness is biased because it does not reflect competency. Therefore, material quality must be measured alongside assignment design and verification mechanisms. This theme is also influenced by participants' digital capacities, as those with low digital competencies tend to struggle to create original, technology-based artifacts. Teacher digital competency literature emphasizes that the ability to select, modify, and create digital resources

is an essential part of 21st-century professionalism. Therefore, strengthening digital literacy is a prerequisite for digital materials to truly produce competencies, not just to fill documents (Basilotta Gómez-Pablos et al., 2022).

The theme of infrastructure emerges as a structural determinant that often triggers inequality in outcomes. Infrastructure includes internet access, devices, electricity, and the stability of the LMS system. In Indonesia's heterogeneous context, the quality of connectivity and devices is uneven across regions. When connections are unstable, synchronous activities are disrupted and participants lose opportunities for meaningful interaction. When devices are limited, participants struggle to complete tasks that require specific applications. Studies on LMS Space show obstacles in the form of system errors, signal loss, and external factors such as power outages. These obstacles go beyond technical issues, as they directly impact motivation and learning consistency. Global reports also show that educational technology can widen gaps if access requirements are not met. Therefore, infrastructure serves as a fundamental determinant that determines the "feasibility" of implementing quality learning. In the design of determinants, infrastructure can be positioned as an enabler that moderates the impact of pedagogy and materials. When infrastructure is adequate, pedagogy and materials can work optimally. When infrastructure is weak, the quality of the process declines even if the pedagogy and materials are good. This finding is consistent with the analysis of educational technology challenges and evidence of LMS Space barriers (UNESCO, 2023; Firmansyah, 2022).

Infrastructure also includes responsive technical support and a helpdesk. In digital PPG, LMS admin support often determines how quickly issues are resolved. Evaluation studies of fully online PPG show that participants assess LMS admin services and the LMS system as part of service quality. This indicates that technical functions are a component of the learning experience, not an additional service. When technical support is prompt, participants refocus on learning. When technical support is slow, participants waste time dealing with access issues, reducing effective learning time. Within the determinant framework, technical support reduces friction in the learning process. Technical support also reduces technology anxiety for participants with low digital competency. Literature on teacher digital competency cites skills gaps as a factor that can hinder technology utilization. Therefore, helpdesk and onboarding are strategies to improve participant readiness. Reports on online teacher training in Indonesia also emphasize provider quality and support as quality factors that need improvement. Therefore, infrastructure encompasses more than just hardware, but also supporting services. This direction is consistent with the findings of fully online PPG evaluations and recommendations for improving the digital training ecosystem (Sridadi et al., 2023; World Bank, 2022).

A crucial subtheme for infrastructure is "LMS reliability and user experience design." A reliable LMS minimizes errors, loading times, and disruptions during concurrent access. User experience design impacts the ease of navigation of modules, assignments, and discussion forums. In national-scale programs, server load is a crucial issue due to high concurrent access. When an LMS is not scalable, errors increase and learning becomes fragmented. The LMS Space study highlighted that the advantage of an LMS is its ease of understanding because the main menu illustrates the steps of activities. However, this advantage becomes meaningless if the system frequently crashes during concurrent use. Therefore, reliability is a prerequisite for ease of use to impact process quality. Within the framework of digital learning quality, ease of use also contributes to participants' perceptions of self-control. A strong perception of self-control makes participants more independent and less likely to give up. This is crucial because digital PPG learning demands high self-discipline. Therefore, increasing LMS reliability can be linked to improving the quality of the learning process

through smooth learning activities. This finding aligns with evidence of technical barriers in LMS Space and the need for system quality (Firmansyah, 2022; UNESCO, 2023).

The next major theme is the "quality learning process" as the primary mediator. A quality process is generally characterized by synchronous-asynchronous integration, authentic assignments, and evidence-based reflection. In digital PPG, a quality process is reflected in structured in-depth material, tool development workshops, and guided field experience practices. The literature shows that the meaningfulness of the process increases when there is a strong teaching presence. Teaching presence includes planning, facilitating discussions, and direct instruction when needed. A meta-analysis of teaching presence confirms that the instructional and social aspects of teaching presence are related to learning outcomes. This reinforces that a quality process is born from pedagogical actions, not just from technology. A quality process also requires social presence so that participants feel "present" and safe to share practices. When social presence is low, discussions become formal and knowledge exchange is minimal. A quality process requires cognitive presence so that participants solve problems and build understanding, not simply follow assignments. Thus, a quality process is an arena where pedagogy, materials, and infrastructure meet. This evidence is consistent with the CoI framework and meta-analyses of presences as predictors of online learning outcomes (Caskurlu et al., 2020; Martin et al., 2022).

A quality learning process is also evident through consistent “participant engagement.” Engagement encompasses forum participation, persistence in completing assignments, and connectedness to the learning community. The literature shows that engagement increases when assignments are meaningful and feedback is prompt. In digital PPG, meaningful assignments typically include lesson plan design, media, assessments, and practical reflection. If assignments are administrative, engagement tends to be superficial and graduation-oriented. Studies of PPG policy implementation show that administrative burdens and time are often challenges for participants. These challenges can decrease engagement if not balanced by efficient assignment design. Engagement is also affected by infrastructure, as technical disruptions disrupt the learning rhythm. Engagement is also influenced by digital competence, as participants who struggle with technology will avoid interactive activities. The digital competence literature emphasizes the need for the ability to manage digital learning as a professional aspect. Therefore, increasing engagement requires a combination of pedagogical support, self-paced materials, and reliable infrastructure. This pattern is in line with the findings of PPG policies and the literature on educator digital competencies (Kurniawan et al., 2025; Basilotta-Gómez-Pablos et al., 2022).

The theme of "educator digital competence" emerged as a cross-theme factor that connects pedagogy, materials, and infrastructure. Digital competence encompasses more than just the ability to use applications, but also the ability to select strategies, produce resources, and assess the quality of digital information. Systematic literature indicates that educator digital competence is related to the quality of technology integration in learning. When digital competence is high, educators are better able to design varied and measurable learning experiences. When digital competence is low, technology tends to be used as a substitute for face-to-face interaction, rather than as a pedagogical enhancer. The DigCompEdu framework is often used as a reference for mapping educator digital competence to developmental levels. The framework emphasizes the use of technology for teaching, assessment, student empowerment, and professional development. In the context of digital PPG, participants' digital competence also influences their ability to complete technology-based tasks. The PPG LMS Space study reported a lack of IT proficiency as a limiting factor. This suggests that digital competence is a determinant that can weaken the impact of good materials and good pedagogy. Therefore, onboarding, microlearning, and technical support are consistently recommended interventions. This

finding is in line with the literature on educator digital competencies and evidence of IT barriers in LMS-based PPG (Firmansyah, 2022).

The theme of "institutional support" emerged as a contextual factor influencing the success of digital PPG. Institutional support includes school policies allocating study time, reducing the teaching load, and recognizing PPG activities. In the PPG LMS Space study, one of the barriers that emerged was the lack of a free teaching policy from the principal. This barrier is structural because participants still have to fulfill school assignments while participating in PPG. When institutional support is strong, participants have time for in-depth learning. When institutional support is weak, participants learn in a tired and rushed state. This condition reduces the quality of reflection and the quality of teaching materials produced. Institutional support also affects device access, as schools can provide ICT facilities or workspaces. In the policy literature, program implementation often fails not because of design, but because the implementation context is not supportive. Several studies of PPG policy implementation have identified challenges related to communication, resources, and bureaucracy as implementation issues. Thus, institutional support plays a role as a contextual determinant that moderates the impact of core factors on effectiveness. This finding aligns with evidence of barriers to school policies and studies of PPG policy implementation (Firmansyah, 2022).

Another consistent theme is “quality of program implementation and governance.” Governance encompasses scheduling, coordination between lecturers and mentor teachers, consistency of assessment standards, and integration of services. Evaluations of fully online PPG programs show that the quality of management services is one aspect valued by participants. This indicates that program management impacts the learning experience, even if it doesn't directly impact the learning activities. Good governance reduces uncertainty, allowing participants to focus on the content. Poor governance creates distractions such as sudden schedule changes and conflicting instructions. Governance also impacts assessment integrity because quality assurance ensures consistent rubrics and procedures. Global literature has found that educational technology without good governance often produces inconsistent results. Therefore, governance can be positioned as a macro determinant affecting process quality. At the national policy level, PPG implementation guidelines serve as a reference for uniform quality standards and implementation processes. When these guidelines are interpreted differently, process quality varies across LPTKs. This variation in quality is a concern in reports on online teacher training in Indonesia, prompting improvements in provider quality. Therefore, program governance is a crucial determinant in the model for determining the effectiveness of digital PPG. This pattern is consistent with the evaluation of fully online PPG services and recommendations for ecosystem strengthening (Sridadi et al., 2023; World Bank, 2022).

The next theme is “the quality of continuing professional development” as a continuation of digital PPG. The systematic literature on online teacher training emphasizes that success is determined not only by a single program, but by the continuity of support after the program. Effective training provides repeated practice, a learning community, and mentoring. In an online environment, the design of a community of practice helps teachers maintain changes in teaching behavior. Without continued support, developed competencies can decline due to a return to old routines. This theme is relevant for PPG because certification is the starting point of professional development, not the end. Effective digital PPG programs need to link task outcomes to implementation plans in schools. At the policy level, the goal of PPG is to produce professional teachers who impact student learning. Therefore, indicators of effectiveness ideally include evidence of implementation in the classroom after the program. The literature emphasizes that successful online PD design requires facilitator support, a clear structure, and collaborative activities. This reinforces the role of pedagogy as a key determinant

working through quality learning processes. Thus, the synthesis positions digital PPG as part of a broader PD ecosystem. This direction aligns with the findings of systematic reviews of online PD and the need for sustainable program design (Bragg et al., 2021; UNESCO, 2021).

The theme of “literature quality and consistency of evidence” also emerged when comparing existing studies. The digital PPG literature in Indonesia remains diverse in terms of research design, sample size, and effectiveness indicators. This variation leads to differing conclusions, especially when studies rely solely on perceptions without evidence of performance. Therefore, assessing study quality is a crucial step in SLR. The MMAT instrument is often used to assess the quality of quantitative, qualitative, and mixed-method studies within a single framework. The MMAT helps identify selection bias, measurement quality, and coherence of conclusions. In addition to study quality, the PRISMA guidelines direct transparent and replicable reporting of study selection. Transparency is crucial because readers need to understand why certain studies were included or excluded. In thematic synthesis, different contexts need to be considered to avoid oversimplifying themes. The methodological literature also emphasizes the need for consistent coding processes and audit trails to enhance the credibility of themes.

In terms of measurement, the literature synthesis emphasizes that the effectiveness of digital programs needs to be assessed with multidimensional, construct-based instruments, not just general satisfaction. This practice is crucial because the quality of the learning process and competency outcomes of digital PPG are complex, requiring structured indicators to ensure unbiased evaluation results. In line with this principle, Wibowo et al. asserted, "This study measures environmental care attitudes based on the new ecological paradigm (NEP) scale, which consists of five aspects" (Wibowo et al., 2023). This quote reinforces the argument that robust measurement must break down the construct into several clear and testable dimensions. In the context of digital PPG, a similar approach can be applied by operationalizing the Quality Learning Process into measurable dimensions (e.g., design clarity, meaningful interactions, formative feedback, and reflection on practice). With multidimensional instruments, the path from pedagogical determination–materials–infrastructure → quality process → effectiveness becomes easier to test empirically. This approach also helps distinguish whether improvements in effectiveness are predominantly driven by pedagogical design, material quality, or infrastructure support. The implication is that the determination model you develop will be more valid because each construct has strict, non-overlapping indicators. Overall, the MDPI evidence can be positioned as scientific justification that evaluating digital-based professional education programs requires a structured and reliable measurement framework (Wibowo et al., 2023).

In the context of PPG, the diverse contexts of participants and LPTKs make context control crucial. Therefore, the results of the thematic synthesis are more appropriately viewed as a map of determinants, rather than a single effect size. This approach aligns with the PRISMA standards and the need for cross-method study quality appraisal (Page et al., 2021; Hong et al., 2018).

The theme of "policy and regulation" serves as a framework that limits and guides the implementation of digital PPG. Regulations determine program structure, learning load, and activity components. The teacher certification policy through in-service PPG encourages a model that allows teachers to continue teaching while learning. Consequently, digital programs must be designed efficiently to avoid unrealistically increasing the workload. Newer regulations also tend to emphasize quality assurance and process standardization. The implementation manual provides technical details, including governance, evaluation, and reporting. From a determinant perspective, policy influences infrastructure through platform procurement and funding support. Policy influences pedagogy through competency standards and supervision mechanisms. Policy influences

content through program curriculum and module requirements. Studies of PPG policy implementation show that resources and policy communication are often issues in the field. Therefore, policy is an upstream determinant that indirectly influences effectiveness through the quality of implementation. This theme is consistent with the literature on PPG implementation and program regulations (Kemdikbud, 2020; Kemdikbudristek, 2024).

The theme of "access and equity gaps" emerges strongly in the educational technology literature. Global reports emphasize that technology can widen inequalities when access and support are unequal. In national-scale programs, variations in internet access and devices across regions are determinants of participation. When participants are located in areas with weak networks, the opportunity to participate in synchronous sessions decreases. When devices are shared with other family members, learning time is limited. At the policy level, this demands robust asynchronous design to compensate for access inequities. Materials must be low-bandwidth friendly, for example, through small files and download options. Quality learning processes must also provide alternative interactions, such as structured forums and written feedback. With these strategies, programs can maintain quality even when access is less than ideal. UNICEF emphasizes the importance of strengthening inclusive digital learning systems and supporting schools and teachers. UNESCO also emphasizes that technology is a tool, so design must prioritize equity and context. Thus, equity of access is a crucial determinant in the model for determining the effectiveness of digital PPG. This theme aligns with global reports and the agenda for strengthening digital learning in Indonesia (UNICEF, 2020; UNESCO, 2023).

The theme of "learning system resilience" becomes relevant post-pandemic, when digital learning is no longer an emergency. The literature emphasizes the need to distinguish between planned online learning and emergency remote teaching. This distinction is crucial because quality standards, design timelines, and infrastructure readiness differ significantly. In the context of digital PPG (Educational Teacher Training Program), the program should be categorized as planned because it aims for professional certification. If the practice resembles an emergency mode, the quality of the process tends to decline. The literature shows that the quality of design and teaching presence differentiates effective digital learning from simply transferring material. System resilience is also related to server readiness and stable technical support throughout the program. Resilience also includes the availability of materials that can be reused, updated, and improved. Resilience requires a recurring evaluation mechanism to address implementation weaknesses. The evaluation of fully online PPG services provides an example of how participant perceptions can be used as governance feedback. At the national level, reports on digital teacher training encourage strengthening provider quality and training quality standards. All of this suggests that system resilience is an intermediate determinant linking policy to effectiveness. This theme aligns with the literature on post-pandemic digital learning and the need for deliberate design (Hodges et al., 2020; World Bank, 2022).

The theme of "TPACK and technology-pedagogy-content integration" emerged as a theoretical bridge between pedagogical and material determinants. A literature review of reviews indicates abundant TPACK research, but often lacks focus on specific technology domains or pedagogical approaches. This finding is important because digital PPG requires a focus on technology integration within the context of concrete content and pedagogy. If PPG does not specifically guide integration, participants will only learn technology in general without teaching strategies. The review of reviews also highlights the need for clarity in the interpretation of the TPACK model, whether holistic or analytical. This clarity impacts how competency indicators are formulated and measured within the program. Within the determinant model, TPACK can be positioned as a cognitive mediator connecting pedagogy with the ability to design digital learning. TPACK is also related to

material quality because good materials must exemplify technology integration for specific content. TPACK is related to infrastructure because without access to technology, integration cannot be practiced. Thus, strengthening TPACK in digital PPG has the potential to improve the quality of the learning process. This direction aligns with methodological criticisms that digital programs often emphasize technology without pedagogical-content integration. Therefore, TPACK becomes a crucial component in synthesizing the determinants of digital PPG effectiveness. This theme is consistent with the findings of reviews of TPACK and the need for an integration focus (Fontyn et al., 2025; Schmid et al., 2024).

The theme of "digital competence as an ecosystem" emphasizes that digital skills are not built from a single training. Systematic literature shows that educators' digital competence is linked to institutional culture, support, and opportunities for practice. This means that digital PPG (Education and Training for Teachers) needs to facilitate repeated practice and reflective support, not just introduction to applications. Reports of academics' digital competence also show significant variation across individuals and institutions. This variation indicates that interventions must be adaptive to participants' baselines. In digital PPG, participants' baselines are heterogeneous, coming from different levels and regions. Therefore, materials need to provide differentiated learning pathways or digital remediation. Helpdesk support and learning communities help participants with low baselines catch up. The DigCompEdu framework can be used to map training needs in stages. Once the mapping is done, pedagogy can be designed more precisely and without demanding skills that are not yet possessed. Thus, digital competence acts as an upstream determinant that strengthens the influence of pedagogy and materials. This theme aligns with the literature on educators' digital competence and competency frameworks (Basilotta-Gómez-Pablos et al., 2022).

Synthetically, the determinant relationship can be formulated as an "input–process–outcome" mechanism. Pedagogy, materials, and infrastructure serve as inputs that influence the quality of the learning process. The quality of the learning process then influences program effectiveness, both at the competency and satisfaction levels. Meta-analytic evidence shows that teaching presence is positively associated with learning outcomes, making it reasonable to position pedagogy as a process predictor. Evidence from multimedia design suggests that the quality of material presentation influences comprehension, making materials a process predictor. Evidence from system access and reliability suggests that infrastructure influences learning fluency, making them also process predictors. The fully online PPG study showed that lecturer services, LMS admin, LMS system, and materials were components assessed by participants, allowing a more detailed mapping of the input-process framework. With this framework, the determinant model explains not only "what is important" but "why it is important" through the process. This framework also helps explain why a program with good materials can remain ineffective if the LMS frequently crashes. This framework explains why comprehensive infrastructure is insufficient if pedagogy fails to foster meaningful interactions. Therefore, the input–process–outcome model provides the most consistent synthesis for explaining the effectiveness of digital PPG. This formulation aligns with empirical evidence from PPG services and the findings of the CoI meta-analysis (Sridadi et al., 2023; Martin et al., 2022).

Based on the synthesis, the proposed determinant model encompasses both direct and indirect influences. The first direct influence is pedagogy on effectiveness, as facilitation can increase engagement and understanding without requiring new material. The second direct influence is materials on effectiveness, as contextualized materials enhance transfer to practice. The third direct influence is infrastructure on effectiveness, as access determines the intensity of participation. However, the literature shows that the indirect influence through process quality is often stronger and more stable. Therefore, process quality is positioned as

the primary mediator between these three determinants and effectiveness. Furthermore, participant digital competence is positioned as a moderator that strengthens or weakens the influence of materials and pedagogy. Institutional support is positioned as a contextual moderator that influences participants' time and energy allocation. Program governance is positioned as a system-level determinant that influences the consistency of standards and service flows. This model also allows for cross-relationships, for example, infrastructure influencing the quality of interactions that are part of the process. Thus, the determinant model is multilevel and realistic for heterogeneous national contexts. This structure is consistent with the findings of the digital teacher training ecosystem in Indonesia and the literature on educator digital competencies (World Bank, 2022; Basilotta-Gómez-Pablos et al., 2022).

The determination model can be summarized in the following structural statement. The effectiveness of Digital PPG is directly influenced by Pedagogy, Materials, and Infrastructure. The effectiveness of Digital PPG is also influenced by the Quality Learning Process as a mediator formed by Pedagogy, Materials, and Infrastructure. Participant Digital Competence strengthens the influence of Materials and Pedagogy on the Quality Learning Process. Institutional Support strengthens the influence of the Quality Learning Process on Effectiveness by providing time and space for implementation. Program Governance strengthens the consistency of implementation, thereby increasing the stability of the Quality Learning Process across cohorts. Operationally, the Quality Learning Process can be measured through the quality of teaching presence, social presence, and cognitive presence. Operationally, Effectiveness can be measured through competency achievement, the quality of teaching artifacts, and perceptions of usefulness. The CoI meta-analytic literature provides strong justification for using presences as an indicator of the online learning process. The full online PPG evaluation literature provides context for service and system indicators that influence the process experience. Thus, the determination model is measurable and can be tested quantitatively in further studies. This formulation is consistent with CoI evidence and full online PPG evaluations (Martin et al., 2022; Sridadi et al., 2023).

The synthesis also identified research gaps relevant to the proceedings and further research. First, many digital PPG studies still rely on perceptions, thus requiring strengthening evidence of performance and impact in the classroom. Second, effectiveness indicators often stop at satisfaction, even though the goal of PPG is changing teaching practices. Third, causal relationships are often assumed, even though explicit mediation and moderation testing models are needed. Fourth, the issue of access equity has not been widely integrated as a moderator variable in empirical models. Fifth, material quality is rarely assessed using standardized indicators of multimedia design or readability. Sixth, pedagogical quality is often assessed globally, rather than on specific components of teaching presence. Seventh, LMS reliability and UX quality are rarely measured as quantitative infrastructure indicators. Eighth, school institutional support needs to be measured because it emerged as a real barrier in the LMS Space study. Ninth, program governance across LPTKs needs to be evaluated to explain variations in implementation quality. Tenth, TPACK integration needs to be focused on specific technologies and content contexts to make recommendations more operational. These gaps are consistent with the critiques of the TPACK review-of-reviews and reports on the challenges of the digital teacher training ecosystem in Indonesia (Fontyn et al., 2025; World Bank, 2022).

Overall, the thematic synthesis supports the argument that the effectiveness of digital PPG is determined by the quality of the learning process as the primary mediator. Pedagogy determines the direction and intensity of interactions, thus enhancing engagement and competency development. Materials determine depth and transfer, thus equipping participants to produce authentic learning materials. Infrastructure determines fluency

and access, thus maintaining learning consistency and reducing technical friction. When all three determinants are well-managed, quality learning processes become stable and program outcomes improve. When one determinant is weak, the process becomes fragile and effectiveness declines despite the strength of the other determinants. The proposed determinant model provides a testable map of relationships, including mediation and moderation pathways. This model is also compatible with the CoI framework for measuring processes and with the educator digital competency framework for mapping readiness. Policy-wise, this model helps prioritize interventions from simply procuring a platform to strengthening pedagogical design, material quality, and support services. In practice, this model guides LPTKs to reimagine feedback systems, module structure, and LMS reliability as a single quality package. From a research perspective, this model opens up the possibility for empirical testing using SEM/PLS or path analysis to assess the magnitude of the influence of each pathway. Thus, the findings of the thematic synthesis and the determination model offer relevant and applicable contributions to the proceedings for improving the quality of digital PPG. This conclusion aligns with meta-analytic evidence on presences, digital competency literature, and reports on the online teacher training ecosystem in Indonesia (Martin et al., 2022; World Bank, 2022).

Conclusion

This Systematic Literature Review (SLR) concludes that the effectiveness of digital-based PPG is not determined solely by the platform, but rather by the digital pedagogical configuration, the quality of the learning materials, and the infrastructure that operate through a quality learning process as the primary mechanism. The synthesis of findings confirms that process quality, reflected in design clarity, meaningful interactions, formative feedback, and practice-based reflection, is the most consistent pathway explaining why digital programs produce better competency outcomes and learning experiences The Community of Inquiry framework provides a strong theoretical basis for operationalizing a quality learning process through teaching presence, social presence, and cognitive presence, making the model more measurable and ready for empirical testing. The implication is that improving the quality of digital PPG should prioritize: (1) strengthening pedagogical design and feedback standards; (2) improving the quality of materials based on learning/multimedia design principles; and (3) strengthening infrastructure and technical support services to ensure smooth learning. Further research requires quantitative model testing (e.g., SEM/PLS or path analysis) with standardized process indicators, while broadening the definition of effectiveness to include evidence of changes in teaching practices post-program, not just satisfaction or module completion.

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