Digital Ecosystem Models in Teacher Professional Development: A Narrative Review of CPD Frameworks (2015–2024)

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Abstract: This study analyzes digital ecosystem models in teacher professional development (CPD) through a narrative literature review of 30 international journal articles published between 2015 and 2024. Using purposive selection and thematic synthesis, the study identifies four interconnected models: digital collaborative professional learning, data-driven and personalized CPD, hybrid and blended CPD ecosystems, and AI-enhanced microlearning CPD. Rather than treating these models as separate approaches, this study reconceptualizes digital CPD as an integrated ecosystem in which collaboration, personalization, hybridity, and AI support operate as interdependent components. The findings show that digital ecosystems expand opportunities for teacher collaboration, adaptive feedback, flexible learning, and personalized support across diverse educational contexts. However, effectiveness depends not only on technological adoption, but also on the alignment between teachers' digital literacy, infrastructure readiness, program design quality, and school leadership. By moving beyond descriptive categorization, this study offers an integrative and explanatory framework for understanding sustainable teacher learning across contemporary educational settings and the digital era.

Abstrak: Penelitian ini menganalisis model ekosistem digital dalam pengembangan profesional guru (CPD) melalui kajian pustaka naratif terhadap 30 artikel jurnal internasional yang diterbitkan pada 2015–2024. Dengan seleksi purposif dan sintesis tematik, penelitian ini mengidentifikasi empat model yang saling terkait: pembelajaran profesional kolaboratif digital, CPD berbasis data dan personalisasi, ekosistem CPD hibrida dan blended, serta CPD berbantuan AI dan microlearning. Alih-alih memandang model-model tersebut sebagai pendekatan terpisah, penelitian ini merekonseptualisasikan CPD digital sebagai ekosistem terpadu di mana kolaborasi, personalisasi, hibriditas, dan dukungan AI bekerja sebagai komponen yang saling bergantung. Temuan menunjukkan bahwa ekosistem digital memperluas peluang kolaborasi guru, umpan balik adaptif, pembelajaran fleksibel, dan dukungan personal dalam berbagai konteks pendidikan. Namun, efektivitasnya tidak hanya ditentukan oleh adopsi teknologi, melainkan juga oleh keselarasan literasi digital guru, kesiapan infrastruktur, kualitas desain program, dan kepemimpinan sekolah. Dengan melampaui kategorisasi deskriptif, studi ini menawarkan kerangka integratif dan eksplanatif untuk memahami pembelajaran guru yang berkelanjutan di era digital serta implikasi praktis bagi sekolah dan pembuat kebijakan.

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A. Introduction

Over the past decade, rapid advances in digital technology have significantly transformed the way teachers learn, collaborate, and develop their professional competencies. The emergence of digital education ecosystems has expanded the possibilities for professional learning by enabling teachers to access flexible, continuous, and context-sensitive development opportunities. Through digital platforms, online collaborative spaces, and adaptive technologies, teachers can now participate in learning processes that are increasingly personalized and responsive to their professional needs (Pangrazio & Selwyn, 2020; Macià & García, 2016; Trust et al., 2018; Manca & Ranieri, 2017; Lantz-Andersson et al., 2018). This transformation reflects a broader global shift in education, where teacher learning is no longer confined to isolated training events but is gradually becoming embedded within dynamic and networked digital environments (Schleicher, 2018).

At the same time, expectations for teachers have expanded substantially. In many education systems, teachers are now expected not only to master subject knowledge and pedagogy, but also to develop digital competencies, adaptive learning skills, and the capacity to respond to rapidly changing instructional demands. Recent studies indicate that digital environments allow teachers to extend their professional networks, use learning analytics to inform instructional decisions, and engage with emerging technologies that support sustained professional growth (Howard et al., 2021; Carpenter & Krutka, 2014; Van Leeuwen et al., 2023; Tondeur et al., 2016). In this sense, digital transformation is not merely changing the tools available for professional development; it is reshaping the very architecture of teacher learning itself.

However, despite these developments, Continuing Professional Development (CPD) in many educational settings still relies heavily on conventional face-to-face training. Such models are often short-term, fragmented, and disconnected from teachers' everyday classroom realities, making them less effective in supporting long-term improvement in teaching practice (Darling-Hammond et al., 2017; Guskey, 2020). As Darling-Hammond et al (2017) argue, professional development frequently lacks continuity, contextual relevance, and meaningful collaboration. These weaknesses are further intensified by uneven levels of teachers' digital literacy, unequal access to technological infrastructure, and limited institutional support for digital collaboration, all of which continue to constrain the effectiveness of CPD implementation (Gudmundsdottir & Hathaway, 2020; Dexter & Richardson, 2020; Scherer & Teo, 2019). As a result, the gap between what teachers need and what professional development typically provides remains a persistent challenge.

Within this context, digital CPD has gained increasing attention as a more flexible and potentially sustainable alternative. Yet the literature still tends to present digital CPD in a fragmented manner. Many studies focus on specific approaches such as professional learning networks, blended learning, microlearning, or artificial intelligence, but do not sufficiently explain how these approaches are connected or how they function together within a broader professional learning system (Trust et al., 2018; Opfer & Pedder, 2011; Kukulska-Hulme, 2022). This fragmented treatment limits conceptual clarity and prevents a deeper understanding of digital CPD as an integrated process rather than a set of isolated practices. In practice, however,

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teacher professional development in digital settings is rarely shaped by a single mechanism alone; instead, it emerges from the interaction of technological, pedagogical, social, and institutional elements.

Despite the growing body of research on digital Continuing Professional Development (CPD), an important conceptual gap remains. Much of the existing literature continues to examine digital CPD components separately, such as professional learning networks, blended learning, microlearning, or artificial intelligence, without fully explaining their interdependence or systemic relationships (Trust et al., 2018; Kukulska-Hulme, 2022; Macià & García, 2016). While these studies contribute valuable insights, they often stop at describing individual practices and do not sufficiently explain how these practices combine to shape a coherent model of professional development. In particular, limited attention has been given to digital CPD as an integrated ecosystem that brings together technology, pedagogy, data use, collaboration, and institutional conditions (Papamitsiou & Economides, 2014; Howard et al., 2021). Consequently, the relational dynamics among these components, and their combined influence on CPD effectiveness, remain underexplored.

A further limitation in previous studies is that they often privilege one dimension of digital CPD while underrepresenting others. For example, studies on professional learning networks emphasize collaboration and teacher interaction but may overlook the role of data and adaptive feedback. Likewise, research on microlearning and artificial intelligence often highlights efficiency and personalization yet gives less attention to the social and organizational conditions required for sustainable implementation (Opfer & Pedder, 2011; Kukulska-Hulme, 2022). As a result, the field lacks a unifying conceptual lens that can explain how collaborative, data-driven, hybrid, and AI-supported approaches operate together within a single professional learning ecology. This omission is significant because the effectiveness of digital CPD is unlikely to depend on any one feature alone, but rather on the alignment among these features and the contexts in which they are embedded.

This study seeks to address these limitations by synthesizing fragmented perspectives into a more coherent, ecosystem-based framework. It maps four majors digital CPD models: digital collaborative professional learning, data-driven and personalized CPD, hybrid and blended CPD ecosystems, and AI-enhanced microlearning CPD. Rather than treating these models as separate categories, the study conceptualizes them as interconnected dimensions of a digital professional development ecosystem. In addition, it identifies key enabling conditions such as teachers' digital literacy, infrastructure readiness, program design quality, and school leadership that shape the successful implementation of digital CPD (Dexter & Richardson, 2020). By linking model types and implementation conditions, this study moves beyond descriptive categorization toward conceptual integration.

The novelty of this study lies in its attempt to reconceptualize digital CPD as a dynamic ecosystem rather than a collection of discrete practices. Specifically, it synthesizes existing approaches into an integrative framework that highlights the interaction between collaboration, personalization, hybridity, and AI support within digital education environments. This framing enables digital CPD to be understood not only in terms of the tools employed, but more importantly in terms of how teachers, technologies, institutions, and

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learning processes interact to produce meaningful and sustained professional growth. In doing so, the study extends conventional CPD perspectives toward a more holistic, adaptive, and digitally informed understanding.

More importantly, this study moves beyond prior research that tends to examine digital CPD components in isolation (Trust et al., 2018; Kukulska-Hulme, 2022; Macià & García, 2016), by explicitly theorizing the relational and interdependent nature of these components within a unified system. Through this perspective, it provides a structural explanation of how different CPD models operate collectively, rather than independently, and how their effectiveness emerges from the alignment between technological, pedagogical, and organizational dimensions. This integrative approach makes it possible to explain why similar digital CPD initiatives may produce different outcomes across contexts, why technologically advanced models do not always lead to effective professional learning, and how misalignment among ecosystem components can result in fragmented or unsustainable practices.

Theoretically, this study contributes to the teacher professional development literature by offering a conceptual foundation that shifts the focus from identifying "what models exist" to understanding "how and why digital CPD functions as an interconnected system." Practically, it provides insights for teachers, schools, and policymakers in designing professional development programs that are more integrated, sustainable, and responsive to contemporary educational realities. In particular, the findings support a shift away from one-off training models toward continuous, contextually grounded, and ecosystem-based professional learning. More broadly, the study responds to global challenges related to digital transformation, evolving pedagogical demands, and increasing pressure for flexibility and scalability in teacher development.

Accordingly, this study aims to identify and map existing digital CPD models within an educational ecosystem, examine their core components and mechanisms, and analyze the factors that influence their implementation effectiveness. The central research questions guiding this study are: (1) What types of digital CPD models emerge from the literature?, (2) What are the core characteristics of these models?, and (3) What factors influence the effectiveness of their implementation?. Through these questions, the study seeks to provide a more integrated and explanatory understanding of how digital professional development operates in contemporary educational contexts and how it may be designed more effectively to support teacher learning in the digital era.

B. Method

This study employed a Systematic Literature Review (SLR) combined with thematic synthesis to examine digital ecosystem models in teacher professional development (Continuing Professional Development/CPD). The SLR approach was selected to ensure a transparent, replicable, and rigorous process in identifying, screening, appraising, and synthesizing relevant studies. The review was structured according to the PRISMA 2020 framework, covering the stages of identification, screening, eligibility, and inclusion. Thematic synthesis was then used to interpret patterns across studies and develop an integrated conceptual understanding of digital CPD as an interconnected ecosystem.

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The literature search covered peer-reviewed journal articles published between 2015 and 2024. Searches were conducted on Scopus, Web of Science, ERIC, and Google Scholar. The search strategy used Boolean combinations of keywords related to digital professional development and teacher learning, including: "digital CPD," "teacher professional development," "digital ecosystem," "professional learning networks," "data-driven learning," "hybrid learning," "blended learning," "microlearning," and "artificial intelligence in education." To ensure transparency and reproducibility, the search and screening process was documented systematically. The initial search retrieved 186 records. After duplicate removal, 144 records remained for title and abstract screening. Of these, 48 full-text articles were assessed for eligibility, and 30 articles met the inclusion criteria and were included in the final synthesis.

The inclusion criteria were: (1) peer-reviewed journal articles, (2) published in English, (3) published between 2015 and 2024, (4) focused on teacher professional development rather than student learning, and (5) explicitly addressing digital, technology-supported, or ecosystem-oriented CPD. The exclusion criteria were: (1) conference proceedings, reports, book chapters, and other non-peer-reviewed publications;

(2) studies not available in full text; (3) studies not written in English; and (4) articles that were not directly relevant to digital CPD, teacher learning, or professional development ecosystems. These criteria were applied to maintain conceptual consistency and methodological rigor across the included studies.

To strengthen the credibility of the review, the selected studies were appraised using adapted criteria based on the Mixed Methods Appraisal Tool (MMAT). Each article was assessed in four dimensions: (1) clarity of the research purpose, (2) methodological rigor, (3) validity of data or analysis, and (4) relevance to digital CPD. Studies that did not demonstrate sufficient conceptual or methodological quality were excluded during the eligibility stage. This appraisal process helped ensure that the final synthesis was grounded in studies with acceptable academic quality.

A structured data extraction matrix was developed to organize information consistently across studies. For each article, the following data were extracted: author(s), year of publication, country or context, research design, digital CPD model or approach, theoretical framing, key findings, and implications. The extracted data was tabulated in a comparative matrix to support cross-study comparison and facilitate the identification of recurring themes, patterns, and conceptual relationships.

The included studies were analyzed using thematic synthesis following the six-step procedure proposed by Braun & Clarke (2006): (1) familiarization with the data, (2) initial coding, (3) theme generation, (4) theme review, (5) theme definition and naming, and (6) final synthesis. The coding process was conducted iteratively to identify similarities and differences across studies.

The analysis was guided by the research questions, enabling the identification of: (1) types of digital CPD models, (2) their core characteristics, (3) the interactions among models within a digital ecosystem, and (4) contextual factors influencing implementation effectiveness. Through this process, the review moved beyond description and generated an

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integrated conceptual framework of digital CPD ecosystems.

Several strategies were used to enhance the trustworthiness of the review. First, explicit inclusion and exclusion criteria were applied to reduce selection bias. Second, the search process and screening stages were documented systematically to create a clear audit trail. Third, coding and theme development were conducted through repeated review and comparison across studies to improve consistency and conceptual coherence. Fourth, the synthesis emphasized transparency in linking findings to the included literature, thereby strengthening the dependability of the review.

The review process followed four sequential stages: identification of relevant studies, screening of titles and abstracts, full-text eligibility assessment, and final inclusion for thematic synthesis. This process is presented in the PRISMA flow diagram to illustrate the pathway from the initial pool of records to the final set of 30 studies included in the review.

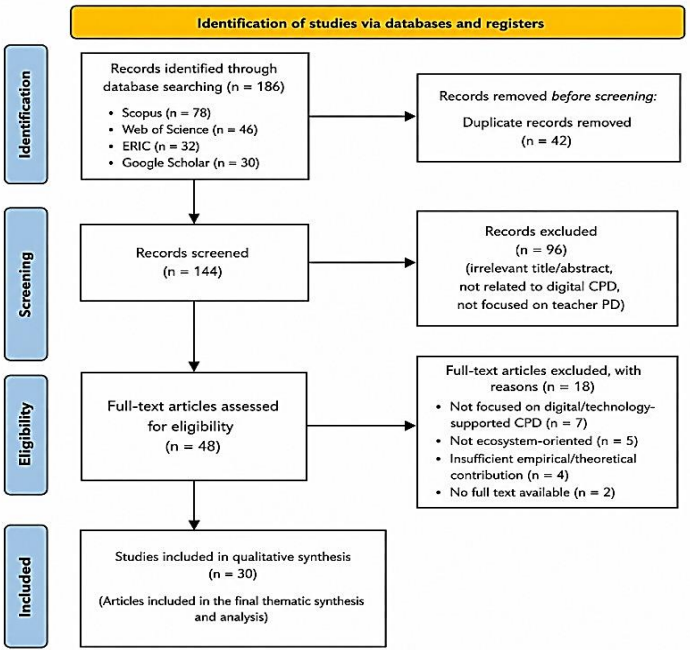

Figure 1. Research Flow of Digital CPD Ecosystem Review

C. Result

This review analyzed 30 peer-reviewed journal articles published between 2015 and 2024 to identify how digital ecosystems shape teacher professional development (CPD). The synthesis shows that digital CPD is no longer represented as a single training format, but as a set of interconnected professional learning arrangements supported by collaboration, data, hybrid learning, and artificial intelligence. According to the reviewed studies, four recurring models emerged: digital collaborative professional learning, data-driven and personalized CPD, hybrid and blended CPD ecosystems, and AI-enhanced microlearning CPD. These findings indicate that digital CPD is increasingly conceptualized as an ecosystem in which technological, pedagogical, and institutional elements interact to support teacher learning in more flexible and continuous ways.

The first research question asked what types of digital CPD models emerge from the

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literature. The synthesis identified four major models. The first is Digital Collaborative Professional Learning, which centers on online communities, professional learning networks, and reflective dialogue. The second is Data-driven and Personalized CPD, which emphasizes learning analytics, dashboards, and adaptive feedback. The third is Hybrid and Blended CPD Ecosystems, which combine digital learning with face-to-face mentoring, coaching, and collaborative reflection. The fourth is AI-enhanced and Microlearning CPD, which uses artificial intelligence and short learning modules to support efficient and flexible teacher learning. Together, these models show a clear diversification of CPD approaches in the digital era rather than the dominance of a single model.

Table 1. Summary of Digital CPD Models Identified in the Review

Digital CPD Model	Main Focus	Core Characteristics	Key Technologies / Mechanisms	Representative Studies
Digital Collaborative Professional Learning	Teacher collaboration	Online communities, professional learning networks, reflective dialogue, peer interaction	Social media platforms, online forums, professional learning networks (PLNs)	Trust et al (2018), Carpenter & Green (2017), Carpenter et al (2021), Manca & Ranieri (2017)
Data-driven and Personalized CPD	Individualized learning	Learning analytics, adaptive feedback, personalized learning pathways, data-informed reflection	Dashboards, analytics systems, adaptive learning platforms	Papamitsiou & Economides (2014), Schildkamp (2019), Van Leeuwen et al (2023), Mandinach & Gummer (2016)
Hybrid and Blended CPD Ecosystems	Learning sustainability	Integration of online learning and face-to-face mentoring, coaching, contextualized practice	Learning Management Systems (LMS), blended learning platforms, mentoring systems	Darling-Hammond et al (2017), Voogt & Pareja Roblin (2012), Howard et al (2021), Philipsen et al (2019)
AI-enhanced and Microlearning CPD	Learning efficiency and scalability	Artificial intelligence support, microlearning modules, automated feedback, flexibility access	AI-based recommendation systems, microlearning platforms, mobile learning apps	Holmes et al (2019), Zawacki-Richter et al (2019), Kukulska-Hulme (2022), Zhai et al (2021)

Among the four, the collaborative and hybrid models appear as the most established forms, while data-driven and AI-enhanced models reflect more recent developments in digital professional learning. This pattern suggests a gradual shift from interaction-centered CPD toward more personalized, adaptive, and intelligent learning systems. In other words, the literature indicates that digital CPD is evolving from social networking and blended support toward more data-informed and technology-mediated formats.

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Table 2. Comparative Overview of Digital CPD Models

Model	Main	Key Learning Mechanism	Representative Studies
Digital Collaborative Professional Learning	Collaboration	Online communities, professional learning networks, reflective dialogue	Trust et al (2018), Carpenter & Green (2017)
Data-driven and Personalized CPD	Personalization	Learning analytics, dashboards, adaptive feedback	Papamitsiou & Economides (2014), Schildkamp (2019)
Hybrid and Blended CPD Ecosystems	Sustainability	Combination of online learning and face-to-face mentoring	Darling-Hammond et al (2017), Philipsen et al (2019)
AI-enhanced and Microlearning CPD	Efficiency	AI support, microlearning modules, personalized prompts	Holmes et al (2019), Kukulska-Hulme (2022)

The second research question examined the core characteristics of the identified models. The findings indicate that each model has a distinct focus, yet all share a common goal of strengthening teacher learning in digital environments. Digital Collaborative Professional Learning emphasizes interaction, reflective dialogue, and knowledge exchange through professional communities and networks, where collaboration serves as a central mechanism for developing professional identity and agency.

Data-driven and Personalized CPD focuses on the use of digital evidence to guide learning. Through dashboards, analytics, and adaptive systems, teachers can monitor progress and identify individual needs, shifting CPD from standardized approaches toward more targeted, self-directed, and feedback-oriented learning.

Hybrid and Blended CPD Ecosystems combine digital access with face-to-face mentoring and coaching, enabling flexible yet contextually grounded learning. This model integrates convenience with pedagogical depth, particularly when digital tools are supported by sustained guidance and reflective practice.

AI-enhanced and Microlearning CPD highlights short, adaptive, and technology-supported learning experiences. Artificial intelligence enables automated feedback and personalized recommendations, while microlearning provides flexible, manageable learning units, making this model efficient and responsive to teachers' time constraints (Kukulska-Hulme, 2022; Kohnke & Moorhouse, 2024).

Taken together, these models represent complementary dimensions of digital CPD. Collaborative CPD emphasizes social interaction, data-driven CPD highlights personalization, hybrid CPD balances flexibility and contextual support, and AI-enhanced CPD prioritizes efficiency and adaptability. This synthesis shows that digital CPD is shaped not by a single approach, but by the integration of social, technological, and pedagogical elements within a dynamic learning ecosystem.

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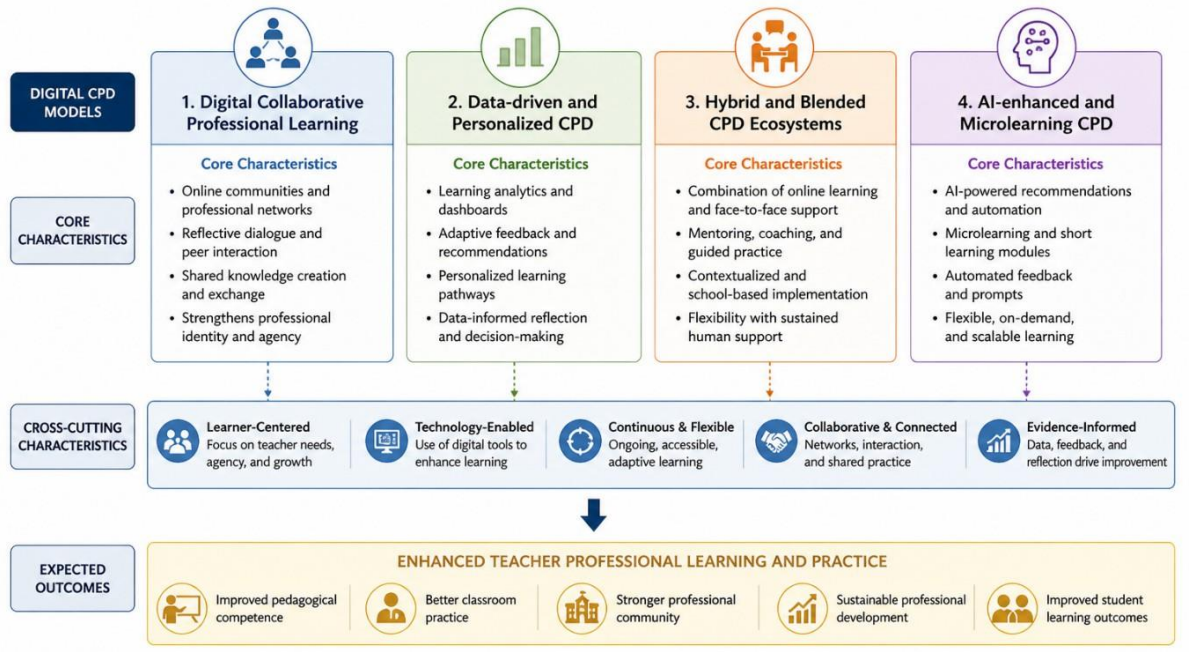

Figure 2. Core Characteristics of Digital CPD Models

The third research question examined the factors influencing the effectiveness of digital CPD implementation. The findings show that implementation success is shaped by several interconnected conditions. Teachers' digital literacy determines their ability to engage meaningfully with digital tools, while infrastructure readiness affects access, connectivity, and continuity. In addition, program design quality influences the coherence, relevance, and sustainability of CPD activities, and school leadership plays a key role in fostering a supportive culture and providing necessary resources. These factors consistently appear across the reviewed studies and jointly shape the success of digital CPD in diverse educational contexts.

These conditions can be grouped into four categories: individual (digital literacy), technological (infrastructure readiness), pedagogical (program design quality), and organizational (school leadership). Importantly, they operate interdependently rather than in isolation. For instance, adequate infrastructure is insufficient without teacher readiness, and well-designed programs require institutional support to be effective. Thus, the effectiveness of digital CPD depends on the alignment between human capacity, technological access, pedagogical design, and organizational support.

Table 3. Factors Influencing the Effectiveness of Digital CPD Implementation

Factor Category	Specific Factor	Influence on Implementation
Individual	Digital literacy	Enables meaningful participation and tool use
Technological	Infrastructure readiness	Supports access and continuity
Pedagogical	Program design quality	Ensures coherence, relevance, and sustainability
Organizational	School leadership	Provides direction, support, and resources

Overall, the results show that digital CPD should be understood as an interconnected ecosystem rather than as a collection of isolated interventions. The four models identified in

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this review represent different but complementary ways of supporting teacher learning in digital environments. Collaboration builds professional relationships and drives instructional improvement (Carpenter al., 2021), data-driven systems support personalization, hybrid structures maintain contextual depth, and AI-enhanced microlearning expands flexibility and scalability. At the same time, the effectiveness of these models depends on teachers' digital literacy, infrastructure readiness, program quality, and leadership support. This synthesis suggests that digital CPD becomes most effective when technological innovation is aligned with pedagogical purpose and organizational readiness.

D. Discussion

The findings of this study suggest that digital Continuing Professional Development (CPD) is more appropriately understood as a dynamic and evolving ecosystem rather than a collection of discrete training approaches. While previous studies have highlighted the role of digital technologies in expanding access and flexibility in teacher learning (Pangrazio & Selwyn, 2020; Macià & García, 2016; Trust et al., 2018; Manca & Ranieri, 2017), the present synthesis demonstrates that these contributions are not isolated developments but are structurally interconnected within broader socio-technical systems. This implies that digital CPD should not merely be interpreted as a technological enhancement of traditional professional development, but as a reconfiguration of how professional learning is organized, sustained, and contextualized.

However, this ecosystem perspective also reveals an important tension. Although the literature consistently promotes digital CPD as flexible, adaptive, and scalable, its effectiveness remains uneven across contexts. Studies emphasizing collaborative learning highlight the benefits of interaction and professional dialogue (Trust et al., 2016; Trust et al., 2018; Carpenter et al., 2021; Manca & Ranieri, 2017; Prestridge, 2019), yet these benefits are often contingent on teachers' willingness and capacity to engage actively in digital communities. In practice, not all teachers participate equally, and issues such as digital fatigue, uneven engagement, and superficial interaction may limit the depth of professional learning. This suggests that collaboration alone does not guarantee meaningful professional development, particularly when not supported by strong facilitation or institutional structures.

A similar limitation can be observed in data-driven and AI-supported CPD models. While these approaches promise personalized learning through analytics and adaptive systems (Papamitsiou & Economides, 2014; Schildkamp, 2019; Zhai et al., 2021; Tammets & Ley, 2023), they also introduce new challenges related to data interpretation, algorithmic bias, and over-reliance on technological systems. Teachers may not always possess the necessary data literacy to interpret dashboards effectively, and automated feedback systems may oversimplify complex pedagogical realities. Consequently, the assumption that personalization inherently improves professional learning should be treated with caution, as its effectiveness depends heavily on teachers' ability to critically engage with data and technology.

Furthermore, the prominence of hybrid CPD models in the findings reinforces the argument that digital transformation does not replace human interaction but rather reshapes

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it. As noted in previous studies (Darling-Hammond et al., 2017; Philipsen et al., 2019), mentoring, coaching, and contextual support remain essential components of effective professional development. The present findings extend this perspective by showing that hybrid models function as a stabilizing mechanism within the digital ecosystem, balancing flexibility with pedagogical depth. Without this balance, fully digital approaches risk becoming fragmented, impersonal, or disconnected from classroom realities.

Another critical insight emerging from this study is the uneven global distribution of digital CPD research. Much of the literature reviewed originates from contexts with relatively strong technological infrastructure and institutional support (Dexter & Richardson, 2020; Gudmundsdottir & Hathaway, 2020; Scherer et al., 2021). As a result, the ecosystem model proposed in this study may reflect an idealized version of digital CPD that is not easily transferable to under-resourced educational settings. In such contexts, limited access to technology, insufficient training, and weak institutional support may significantly constrain the implementation of digital CPD initiatives. This raises important questions about equity and scalability, suggesting that the success of digital CPD cannot be separated from broader structural conditions.

Taking together, these findings indicate that the effectiveness of digital CPD lies not in the adoption of specific models, but in the alignment between technological innovation, pedagogical design, and organizational readiness. This aligns with broader theoretical perspectives emphasizing the systemic nature of educational change (Desimone, 2009; Guskey, 2020; Scherer et al., 2019) but extends them by highlighting how digital environments intensify the interdependence among these elements. In this sense, digital CPD should be understood as a complex adaptive system, where outcomes emerge from the interaction between human actors, technological tools, and institutional contexts.

Importantly, this study moves beyond prior research by integrating collaborative, data-driven, hybrid, and AI-enhanced approaches into a single conceptual framework. While earlier studies have tended to examine these dimensions separately (Trust et al., 2018; Kukulska-Hulme, 2022; Macià & García, 2016), the present synthesis demonstrates that their combined interaction provides a more comprehensive explanation of how digital professional learning operates. This integrative perspective offers a more robust conceptual foundation for future research and practice, particularly in designing CPD models that are both technologically innovative and pedagogically meaningful.

E. Implication

The findings imply that teacher professional development in the digital era should be designed as an integrated ecosystem rather than as isolated training activities. This requires aligning teacher digital competence, technological infrastructure, program design, and institutional support to ensure effectiveness and sustainability. Practically, schools should adopt a holistic approach by combining collaborative learning communities, data-driven personalization, hybrid learning structures, and AI-supported microlearning to address diverse teacher needs while maintaining flexibility and contextual relevance. At the same time, strengthening leadership capacity and ensuring equitable access to digital resources are

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essential to support implementation across different contexts. More broadly, these results highlight that the success of digital CPD depends not only on technological adoption, but on the coherence between pedagogical purpose, human capacity, and organizational readiness, making systemic integration a key priority for future professional development initiatives.

F. Limitation and Suggestion for Further Research

Despite offering an integrated perspective on digital CPD as an ecosystem, this study has several limitations that should be acknowledged. First, although a systematic approach was applied, the review relies on a qualitative synthesis of 30 journal articles, which may not fully capture the breadth and diversity of global research on digital professional development. Second, the analysis is based on published studies that predominantly originate from contexts with relatively strong technological infrastructure, which may limit the applicability of the findings to settings with different levels of digital readiness. Third, as with most literature-based studies, the interpretation of themes is inherently influenced by the researcher's analytical perspective, even though efforts were made to ensure consistency and transparency.

Building on these limitations, future research should extend this work by adopting more comprehensive and comparative approaches, such as large-scale systematic reviews or meta-analyses that incorporate a wider range of databases and contexts. Empirical studies are also needed to examine how the identified digital CPD models operate in real educational settings, particularly in under-resourced environments where infrastructure and digital literacy remain critical challenges. In addition, longitudinal research could provide deeper insights into how data-driven and AI-supported CPD influence teacher practices and learning outcomes over time. Finally, further studies should explore how different components of the digital CPD ecosystem can be effectively integrated, with particular attention to contextual adaptation, equity, and sustainability, so that professional development initiatives can respond more effectively to the complex demands of contemporary education.

G. Conclusion

This study concludes that digital Continuing Professional Development (CPD) is most effectively understood as an interconnected ecosystem that integrates multiple approaches rather than relying on a single model. The identification of collaborative, data-driven, hybrid, and AI-enhanced CPD highlights that teacher professional learning in the digital era is inherently multi-dimensional, combining social interaction, personalization, flexibility, and technological responsiveness. These dimensions work together to support more continuous, adaptive, and context-sensitive forms of learning, reflecting a shift away from fragmented and short-term training practices.

At the same time, the effectiveness of digital CPD is not determined solely by the availability of technology, but by the alignment between teacher capacity, infrastructure readiness, program design, and institutional support. This reinforces the idea that digital transformation in professional development is fundamentally systemic, requiring coherence between pedagogical goals, human resources, and organizational conditions.

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Overall, this study contributes to a more integrated understanding of digital professional development by framing CPD as a dynamic ecosystem shaped by the interaction of models, characteristics, and contextual factors. This perspective not only clarifies how digital CPD operates in contemporary educational settings, but also provides a foundation for designing more coherent, inclusive, and sustainable professional development initiatives. Moving forward, the challenge lies in translating this ecosystem perspective into practice, ensuring that digital CPD initiatives are not only technologically advanced but also pedagogically meaningful and contextually responsive.

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