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A Training Model Framework to Professional Development for Teachers: A Cross-National DigCompEdu Reloaded Approach in Artificial Intelligence, Online and Open Education

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Abstract

The expansion of digital learning ecosystems, coupled with the growing presence of Artificial Intelligence, online education and open education, has highlighted the need for new models of professional development for teachers. Recent studies carried out in Portugal and Brazil, based on the Pedagogical DigCompEdu Reloaded framework, have identified significant weaknesses in teachers' digital pedagogical competences in these emerging fields. Against this backdrop, the aim of this study is to present the design of a professional development model conceived to address the identified training needs. The research follows a Design-Based Research approach and constitutes the second phase of a broader international project, focusing on the design of an educational artefact underpinned by empirical evidence and theoretical grounding. The model was developed based on the results of diagnostic studies carried out in Portugal and Brazil, the international literature on teachers' professional development, and the conceptual framework of Pedagogical DigCompEdu Reloaded. Grounded in an ecological perspective on digital education, the model is organised around five design principles: competence-based orientation, flexibility through microlearning, the promotion of open educational practices, practice-based experimentation, and the reflective and ethical use of Artificial Intelligence. The proposal incorporates a development framework comprising three progressive levels and three learning pathways dedicated to Artificial Intelligence, Online Education and Open Education, delivered through micro-credentials, MOOCs and communities of practice. The study presents a model of professional development grounded in both empirical and theoretical evidence, the future implementation of which will enable an assessment of its contribution to the creation of sustainable professional learning ecosystems and to the critical, ethical and pedagogically meaningful integration of digital technologies into education.

Keywords: teacher professional development; digital competences; artificial intelligence in education; online education; open education; design-based research

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1. Introduction

The increasing digitalisation of educational ecosystems has been profoundly transforming the contexts in which teachers and students teach, learn and construct knowledge. The expansion of virtual learning environments, the development of new forms of interaction and communication, and the emergence of increasingly sophisticated cognitive

technologies have helped to redefine the role of teachers and the competences required for teaching in the 21st century.

In this context, digital pedagogical competences are becoming increasingly important as a central element of teachers' professional development. The pedagogical use of digital technologies is no longer limited to the integration of technological resources within the classroom context; it now involves the creation of learning experiences in hybrid and virtual environments, the promotion of participation in collaborative and knowledge-sharing networks, the critical use of open educational resources and, more recently, the integration of artificial intelligence systems into educational processes.

Developments in these contexts have also highlighted the need to update the frameworks for teachers' digital competence. In this regard, Pedagogical DigCompEdu Reloaded (Moreira et al., 2024) emerges as an evolution of the European DigCompEdu framework, incorporating competences related to emerging areas that are becoming increasingly relevant in contemporary education systems, namely Open Education, Online Education and Artificial Intelligence. The inclusion of these dimensions stems from the recognition that the current challenges of digital education require competences that were not sufficiently addressed in previous models of teachers' professional development.

At the same time, recent studies carried out in Portugal and Brazil based on this framework have identified significant training needs precisely in these emerging fields, highlighting particularly pronounced weaknesses in competences related to Artificial Intelligence, Open Education and Online Education (Dias-Trindade et al., 2025; Moreira et al., 2025).

Despite the growing body of academic literature devoted to assessing teachers' digital competences, there remains relatively little research that systematically describes how these needs can be translated into structured professional development programmes. It is within this context that the present study is situated, forming part of a broader research programme carried out within the framework of two international research projects, the aim of which is to present and underpin the pedagogical design of a training programme developed on the basis of the needs identified by the Pedagogical DigCompEdu Reloaded framework. Thus, the theoretical foundations and pedagogical principles that guided its development will be explained, with a view to contributing to reflection on training models suitable for teachers' professional development.

Despite the growing number of studies dedicated to assessing teachers' digital competences and identifying their training needs, research seeking to translate this diagnostic evidence into structured, coherent and sustainable models of professional development remains relatively limited. Much of the literature focuses on measuring competences or describing specific training initiatives, whilst studies that systematically describe the transition from diagnosis to the design of integrated training models are less common. It is this gap that the present study seeks to address.

The identification of this research gap should be understood as a preliminary framing of the problem rather than as the outcome of a comprehensive literature review. A more detailed examination of existing professional development models and related research is presented in Section 2. Therefore, the highlighted gap is further substantiated through the subsequent analysis of the literature, which reveals the limited availability of integrated frameworks simultaneously addressing Artificial Intelligence, Online Education, Open Education and pedagogical-digital competence development within a coherent professional development architecture.

2. Pedagogical-Digital Competences and Emerging Needs in Teacher Training

2.1. Pedagogical DigCompEdu Reloaded and the Evolution of Teachers' Digital Competences

The digital transformation of education has significantly broadened the concept of teachers' digital competence. Whilst early models focused primarily on the pedagogical use of digital technologies and the integration of technological resources into teaching and learning processes, more recent developments present additional challenges relating to the openness of educational processes, learning in online environments and the growing presence of intelligent systems in educational ecosystems.

It was against this backdrop that Pedagogical DigCompEdu Reloaded emerged; as mentioned, this is an update to the European DigCompEdu framework (Redecker, 2017), developed to meet the demands of today's digital learning contexts. Whilst retaining the four core pedagogical areas of the original model, this framework "incorporates into the four areas of the pedagogical dimension new competences related to Open Education, Online Education and Generative Artificial Intelligence" (Moreira et al., 2024, p. 13).

Open Education presupposes that teachers can locate, adapt, create and share educational resources, promoting practices based on collaboration, participation and the democratisation of knowledge (Inamorato dos Santos et al., 2016). Online education requires competences relating to the design of learning experiences in digital environments, the management of synchronous and asynchronous interactions, the building of virtual learning communities, and the implementation of assessment strategies suited to online contexts (Santos, 2023). In turn, Artificial Intelligence is emerging as one of the most challenging areas in contemporary education, requiring teachers to understand how these technologies work, to be able to interpret and critically evaluate their results, and to integrate these systems into educational processes in an ethical and pedagogically sound manner (Bekiaridis, 2024; Tuomi, 2024).

In this sense, rather than simply adding new areas to teachers' work, these areas represent transformations in the processes of teaching, learning, assessment and participation in digital environments. Consequently, they require renewed forms of professional development capable of supporting teachers in building new pedagogical competences.

2.2. Initial Training, Professional Development and Emerging Areas

The importance of these areas becomes particularly evident when one considers that a significant proportion of teachers currently in post undertook their initial training before these fields emerged on the educational scene. As Dias-Trindade and Ferreira (2022) note, many teachers completed their training at a time when the pedagogical integration of digital technologies still occupied a relatively minor place in teacher training curricula and when issues relating to Digital Education were not included in the available training programmes. As these authors point out,

> this situation meant that many teachers, faced with the technological developments of the last twenty years—which have brought new equipment, new resources and, above all, new possibilities into schools within a hyperconnected and multimodal world—found themselves needing to seek training that would give them the confidence to innovate. (Dias-Trindade & Ferreira, 2022, p. 314)

This need is confirmed by recent studies carried out in Portugal (Dias-Trindade et al., 2025) and in Brazil (Moreira et al., 2025). In the case of Portugal, the data show that only 31.7% of participants were under 49 years of age, whilst 82.1% had more than twenty years' professional experience. In Brazil, the situation is slightly different; however, 20.2% of participants were over 50 years of age and 26% had more than twenty years' teaching experience.

These results suggest that, particularly in Portugal, a substantial proportion of the teaching staff completed their initial training long before the current digital learning ecosystems were established. It is important, however, to emphasise that this situation should not be interpreted as resistance to innovation or an inability to adapt to technological changes. On the contrary, these studies reveal that many teachers demonstrate adequate levels of competence in the areas traditionally covered by digital teaching competence frameworks, in line with the findings presented by Lucas and Bem-Haja (2024) and by Palacios-Rodríguez et al. (2025) regarding Portuguese and Spanish teachers. The challenge lies primarily in the rapid emergence of new areas that require continuous professional development.

In this context, such training plays a strategic role as a mechanism for updating and developing the competences needed to meet the demands of new educational scenarios.

2.3. Empirical Evidence on Training Needs in Portugal and Brazil

Studies carried out in Portugal and Brazil using the Ped_DigCompEdu_Red24 scale provide a more detailed understanding of the main professional development needs of teachers associated with the emerging areas of the framework.

The results show that teachers demonstrate relatively consistent levels of competence in the dimensions originally covered by DigCompEdu, as confirmed by other studies which have identified the positive effects of various training initiatives focused on teachers' digital competences (Lucas & Bem-Haja, 2024; Palacios-Rodríguez et al., 2025; Gallego Joya et al., 2025). However, when the competences associated with the new areas incorporated by Pedagogical DigCompEdu Reloaded are analysed, a significant reduction in proficiency levels is observed. In Portugal, more than half of the responses relating to the new competences are at level A1 (55.7%), whilst in Brazil this figure stands at 39.9% (Dias-Trindade et al., 2025; Moreira et al., 2025).

Analysis of the three emerging areas highlights particularly significant weaknesses. Among Portuguese teachers, 72.7% are at level A1 in terms of competences related to Artificial Intelligence, whilst 52.5% are at the same level in Open Education and 44.3% in Online Education. A similar pattern is observed amongst Brazilian teachers, with 57.7% of participants at level A1 in Open Education and 52.8% in Artificial Intelligence.

The situation regarding Artificial Intelligence is particularly significant. Taking Portuguese and Brazilian participants together, 79.5% are at levels A1 and A2 in this field, whilst only 3.6% have reached the highest proficiency levels. These results suggest the existence of particularly significant training needs in an area whose presence in educational processes has been growing rapidly.

At the same time, the similarity of the results obtained in the two countries suggests that these needs are not phenomena specific to a national context but cross-cutting challenges associated with the integration of emerging areas of digital education into contemporary educational processes. Furthermore, the data suggest that the competences associated with the emerging areas identified by Pedagogical DigCompEdu Reloaded currently represent one of the greatest weaknesses in teachers' digital preparedness. Rather than technological gaps, these results reveal training needs relating to complex pedagogical dimensions, including the creation of resources supported by artificial intelligence, assessment in digital contexts, the critical use of intelligent systems, participation in open educational practices, and the design of online learning experiences. These results reveal limitations in the capacity to understand, regulate, and pedagogically integrate new forms of agency that increasingly participate in the construction of knowledge. This situation becomes even more concerning when considering that the results relating to Online Education, although slightly higher than those for AI, remain concentrated at the lower levels of digital competence (Dias-Trindade & Moreira, 2026, p. 13).

Table 1 illustrates the different roles played by the studies considered in this investigation. The first group of studies provides the theoretical and empirical foundations supporting the relevance of pedagogical-digital competence development and teacher professional development in digitally mediated educational contexts. In contrast, the studies conducted in Portugal (Dias-Trindade et al., 2025) and Brazil (Moreira et al., 2025) constitute the direct empirical basis for the design of the proposed model. Both pilot studies employed the Pedagogical DigCompEdu Reloaded framework and revealed convergent patterns of professional development needs, particularly in domains associated with Artificial Intelligence, Online Education and Open Education. These findings informed the definition of the model's domains, learning pathways, pedagogical principles and progressive levels of development. Consequently, the proposed model emerges from the integration of theoretical knowledge and empirical evidence obtained from two complementary educational contexts.

Table 1. Studies' contribution to the development of the proposed model.

Study	Main Focus	Contribution to the Proposed Model
Lucas and Bem-Haja (2024)	Evaluation of teacher digital competence training programmes	Supports the need for structured, scalable and sustainable professional development initiatives for teachers.
Dias-Trindade and Ferreira (2022)	Relationship between teacher professional development and digital technologies	Highlights the importance of continuous professional development for meaningful pedagogical integration of digital technologies.
Palacios-Rodríguez et al. (2025)	Macroassessment of teachers' digital competences in Spain and Portugal	Provides comparative evidence regarding teachers' digital competence development and reinforces the relevance of competence-based professional development frameworks.
Dias-Trindade et al. (2025)	Assessment of Portuguese teachers' pedagogical-digital competences using the Pedagogical DigCompEdu Reloaded framework	Identified competence gaps and professional development needs that directly informed the design of the proposed model.
Moreira et al. (2025)	Assessment of teachers' pedagogical-digital competences in Paraná (Brazil) using the Pedagogical DigCompEdu Reloaded framework	Identified competence gaps and professional development needs that directly informed the design of the proposed model.
Proposed model	Professional development architecture	Integrates theoretical foundations, the Pedagogical DigCompEdu Reloaded framework and evidence obtained from the Portuguese and Brazilian pilot studies.

2.4. Continuing Professional Development and the Development of Emerging Competences

The evidence identified in the studies presented above is consistent with the international literature on teachers' professional development. (Palacios-Rodríguez et al., 2025) have demonstrated that participation in training programmes specifically tailored to teachers' concrete needs is one of the variables with the greatest impact on the development of teachers' digital competences. Similarly, (Lucas & Bem-Haja, 2024) highlight that structured training programmes aligned with participants' professional needs contribute significantly to the development of their digital competence levels.

For their part, Figueroa-Vargas and Casillas-Martín (2024) argue that processes of innovation in teacher training require consistent coordination between curriculum design, institutional support, monitoring of training pathways and mechanisms for continuous as-

sessment, emphasising that the mere provision of technological resources does not, in itself, lead to the transformation of teaching practices.

In this context, it becomes clear that the development of pedagogical and digital competences in emerging areas cannot be viewed as a one-off process or as the sole responsibility of initial teacher training. The pace of technological change, the growing presence of artificial intelligence in teaching and learning processes, and the consolidation of practices associated with Open Education and Online Education call for systematic programmes of continuing professional development that integrate diverse formats—such as microlearning, MOOCs and communities of practice—capable of supporting teachers in developing new knowledge, competences and pedagogical practices.

Contemporary approaches to teacher professional development tend to bring together different modes of learning, combining flexibility, accessibility and collaboration. In this context, microlearning, Massive Open Online Courses (MOOCs) and Communities of Practice emerge as complementary strategies to meet the demands of lifelong learning within constantly evolving digital ecosystems. Microlearning is based on the provision of content in small learning units, tailored to specific needs and contexts where knowledge is rapidly updated. According to Theo Hug, cited by Garshasbi et al. (2021), it corresponds to "an abbreviated manner of expression for all sorts of short-term learning activities with micro-content" (p. 227), constituting an approach particularly well-suited to the development of emerging competences through flexible, personalised pathways tailored to the participants' pace. This strategy has also been linked to a reduction in cognitive overload and to facilitating the retention of learning (Garshasbi et al., 2021; Job & Ogalo, 2012; Giurgiu, 2017).

On a broader scale, MOOCs have established themselves as a relevant format for teachers' professional development, combining accessibility, openness and opportunities for continuous learning. As Mir and Khan (2026) note, these courses contribute to "increasing accessibility, encouraging lifelong learning, and challenging traditional educational frameworks by offering affordable and flexible alternatives" (p. 2), enabling teachers from different backgrounds to access training programmes tailored to their needs. However, research shows that their effectiveness depends heavily on the pedagogical design, the modular organisation of content, the quality of resources, the promotion of interaction, and the existence of monitoring and feedback mechanisms (Despujol et al., 2022; Azevedo et al., 2024).

Complementing these approaches, Communities of Practice play a fundamental role in consolidating and deepening learning. Defined by Wenger (2011) as groups of people who share common interests or concerns and who learn through regular interaction, these communities promote continuous processes of sharing, reflection and the collaborative construction of knowledge. From this perspective, learning transcends the boundaries of formal courses and develops through the networks of relationships and collaboration established amongst participants. As Dias (2013) emphasises, "social and cognitive immersion is thus the defining feature of the shift towards the collaborative construction of learning and knowledge networks in virtual and communities of practice" (p. 5). Together, microlearning, MOOCs and Communities of Practice form learning ecosystems capable of integrating scientific updates, professional development and the collaborative construction of knowledge, responding to the challenges posed by Open Education, Online Education and Artificial Intelligence in the continuing professional development of teachers.

The decision to integrate microlearning, MOOCs and communities of practice therefore stems not only from their growing relevance in the literature on teacher professional development. These choices respond directly to the needs identified in studies carried out in Portugal and Brazil, which reveal a strong need for continuous professional development amongst participants. The need to ensure scalability and accessibility for teachers working in

different institutional contexts underpins the integration of MOOCs. In turn, the importance attached to experimentation, reflection on practice and collaborative support during processes of pedagogical change justifies the creation of communities of practice as a permanent mechanism for sustaining the learning achieved throughout the training programmes.

It is within this framework that the training model presented in this study is situated; it is based on the idea that teachers' professional development should be understood as a continuous, modular and open process, promoting the development of competences aligned with the challenges of contemporary education.

Although there are various models of teacher professional development described in the literature, most are focused on general digital competences or on specific contexts of technology integration. The model proposed here is distinguished by its integration of empirical evidence gathered from different educational contexts with the Pedagogical DigCompEdu Reloaded framework and with three emerging domains of particular relevance to contemporary education: Artificial Intelligence, Online Education and Open Education. This integration seeks to simultaneously address the challenges of technological updating, pedagogical innovation and the sustainability of teachers' professional development.

Existing professional development models in digital education have typically focused on one or more specific dimensions, including digital competence development, online teaching practices, open educational resources, or more recently, Artificial Intelligence in education. While these approaches have generated valuable contributions, they are often developed around isolated domains or specific institutional contexts. The model proposed in this study seeks to extend previous approaches by integrating the Pedagogical DigCompEdu Reloaded framework with three emerging domains of growing relevance to contemporary education, namely Artificial Intelligence, Online Education and Open Education. Furthermore, unlike models derived primarily from conceptual or policy-oriented frameworks, the proposed architecture is informed by convergent empirical evidence obtained from diagnostic studies conducted in two educational contexts. This combination of empirical grounding, multidimensional scope and progressive professional development pathways constitutes a distinctive feature of the proposed model.

Together, the reviewed studies support the research gap outlined in the Introduction by highlighting the absence of professional development models integrating these domains within a unified pedagogical framework.

3. Methodology

3.1. Research Design

This study forms part of a wider research programme carried out within the framework of two international projects, in Portugal and Brazil, dedicated to the analysis and development of the digital competences of teachers in the public secondary education and higher education sectors. Within the overall structure of the projects, this study corresponds to the second stage of the research process, following an initial phase of diagnosis and mapping of teachers' pedagogical and digital competences and preceding future phases of implementation, validation and evaluation of the training models devised.

Given the nature of the problem under investigation and the defined objectives, a methodological approach based on Design-Based Research (DBR) was adopted. This methodology has established itself as one of the most suitable approaches for investigating complex problems in real educational contexts, particularly when the aim is to link the production of scientific knowledge with the development of innovative solutions for practice. Unlike methodologies focused exclusively on the description or explanation of educational phenomena, DBR seeks to understand emerging problems, devise theoretically grounded

solutions, implement them in authentic contexts, and generate design principles that can be transferred to other educational settings.

Design-Based Research emerged in the early 1990s through the pioneering work of Brown (1992) and Collins (1992) and subsequently established itself as a methodological approach particularly well-suited to the development and refinement of educational interventions in authentic contexts.

With reference to Reeves (2006), Wang and Hannafin (2005) and the Design-Based Research Collective (2003), which is characterised by the interplay between theory, practice and innovation, through iterative cycles of analysis, design, implementation, evaluation and refinement, the research is not limited to observing the educational reality but takes on an interventionist dimension aimed at transforming practices. This characteristic makes DBR particularly well-suited to addressing the challenges arising from the current digital transformation of education, marked by the emergence of Artificial Intelligence, Online Education and Open Education.

The adoption of this methodology is further justified because the aim of this study is not merely to identify gaps in teachers' digital competence but, above all, to transform the evidence produced in the previous research phase into a structured model of continuous professional development capable of addressing the identified needs. Thus, the main outcome of this phase is not a set of isolated training activities but the design of an educational object, understood as a model for teachers' professional development grounded in the Pedagogical DigCompEdu Reloaded framework.

The project follows the general structure of DBR proposed by Reeves (2006), organised into four major interdependent phases: (a) analysis of the problem in a real-world context; (b) development of solutions grounded in theory and supported by empirical evidence; (c) implementation and testing of the solutions in authentic contexts; and (d) reflection, evaluation and formulation of design principles.

This article focuses specifically on the second phase of this cycle, which corresponds to the design of the teacher professional development model. However, this stage cannot be understood in isolation, as it stems directly from the findings generated during the previous diagnostic phase.

The first stage of the project involved administering the Pedagogical DigCompEdu Reloaded Self-Assessment Scale to teachers in Portugal and Brazil. This instrument was developed to expand the European DigCompEdu framework, incorporating emerging competences related to Artificial Intelligence, Online Education and Open Education. The results revealed very similar patterns in both national contexts, demonstrating that the challenges faced by teachers transcend local specificities and reflect broader transformations in contemporary educational ecosystems.

The studies carried out showed that, although teachers demonstrate moderate levels of competence in various areas traditionally covered by DigCompEdu, significant weaknesses persist in emerging competences associated with the pedagogical integration of artificial intelligence, the design of online learning experiences, the facilitation of online communities, the use of open educational resources and the implementation of open pedagogical practices. A low level of proficiency was also identified in areas relating to the personalisation of learning and AI-supported assessment.

From a DBR perspective, these results constituted the problem analysis phase and provided the empirical basis necessary to guide all the design decisions presented in this study.

It is important to clarify that the use of evidence from Portugal and Brazil was not intended to carry out a comparative analysis of national education systems. The aim was to identify converging patterns of teacher professional development needs in different

educational contexts and to use this evidence as a basis for designing a flexible and potentially transferable model. Although there are significant contextual differences between the two countries, this research focused on identifying common challenges relating to the development of pedagogical and digital competences, and the integration of Open Education, Online Education and Artificial Intelligence into teaching and learning processes.

The identification of convergent professional development needs was based on a comparative examination of the results obtained in the two diagnostic studies. Rather than comparing educational systems or institutional arrangements, the analysis focused on the relative distribution of competence levels within the three emerging domains incorporated into the Pedagogical DigCompEdu Reloaded framework. Convergences were established when both studies revealed similar patterns of lower proficiency and recurring developmental needs in the areas of Artificial Intelligence, Online Education and Open Education. At the same time, contextual differences between Portugal and Brazil were not ignored. Instead, they were considered as part of the interpretation of the findings and reinforced the decision to design a flexible model capable of being adapted to different educational settings. Consequently, the model should not be understood as a response to a single national reality but as a design proposal informed by recurring patterns identified within the specific participant groups involved in the two studies.

Based on the identified needs, a continuing professional development model was developed, explicitly designed to address the challenges highlighted in the diagnostic assessment. In line with the principles of DBR, the design process was guided simultaneously by empirical evidence, theoretical underpinnings and practical considerations relating to the contexts of teachers' professional development.

The development of the model drew on three main sources of evidence: the results of empirical studies carried out in Portugal and Brazil (Dias-Trindade et al., 2025; Moreira et al., 2025) using the Pedagogical DigCompEdu Reloaded framework; the international scientific literature on teacher professional development, digital competences, online education, open education and artificial intelligence in education; and the conceptual framework of Pedagogical DigCompEdu Reloaded itself, particularly the emerging competences introduced in the reference framework (Moreira et al., 2024).

The design process, as described in the following section, sought, above all, to ensure a strong link between identified needs, training objectives, competences to be developed, pedagogical methodologies, and mechanisms for monitoring and assessing learning. Rather than merely addressing identified gaps, the aim was to create the conditions for teachers to develop flexible, contextualised and sustainable learning pathways, capable of fostering the continuous development of their pedagogical and digital competences. With this in mind, the model was designed not as a fragmented set of training activities but as an integrated professional development ecosystem comprising different learning modalities, including microlearning and MOOCs.

The Model Design Process

The model design process unfolded in four sequential stages. In the first stage, an integrated analysis was carried out of the results obtained from the diagnostic studies conducted in Portugal and Brazil, with the aim of identifying converging patterns of training needs. In the second stage, these needs were grouped into priority areas of professional development relating to Artificial Intelligence, Online Education and Open Education. In the third stage, the empirical findings were linked to the international literature on teachers' professional development and to the emerging competences defined in the Pedagogical DigCompEdu Reloaded framework, enabling the identification of guiding principles for the design of the model. Finally, in a fourth stage, the training pathways, learning formats and

multi-level architecture of the model were defined, seeking to ensure alignment between the identified needs, the competences to be developed, pedagogical strategies and mechanisms for monitoring learning.

To ensure methodological consistency throughout the design process, the empirical evidence generated in the Portuguese and Brazilian diagnostic studies was subjected to a comparative analysis focused on identifying convergent patterns of professional development needs. Rather than considering isolated indicators, the analysis concentrated on competence domains that consistently revealed lower levels of proficiency across both contexts, particularly in Artificial Intelligence, Online Education and Open Education. These domains were prioritised because they simultaneously exhibited lower competence levels and represented areas of increasing relevance within contemporary digital education ecosystems. The selection of the model's pedagogical and structural components was guided by the alignment between the identified needs, the competences defined in the Pedagogical DigCompEdu Reloaded framework and evidence from the literature on teacher professional development. Consequently, design decisions concerning the thematic pathways, the three-level architecture, and the integration of microlearning, MOOCs and communities of practice were made with the explicit purpose of ensuring coherence between diagnosed needs, intended learning outcomes and sustainable professional development strategies.

3.2. The Educational Artefact: Model for Teachers' Professional Development

In the tradition of Design-Based Research, the products resulting from the research process often take the form of educational artefacts designed to address problems identified in authentic contexts and, at the same time, to generate knowledge that can be transferred to other contexts (Reeves, 2006; Design-Based Research Collective, 2003). These artefacts can take various forms, including pedagogical models, learning environments, educational resources, training programmes or guiding principles for educational intervention.

In this study, the main outcome of the design phase is the development of an educational artefact in the form of a model for teachers' professional development in the emerging fields of Artificial Intelligence, Online Education and Open Education, structured around the Pedagogical DigCompEdu Reloaded framework. More than just a set of training activities, this artefact constitutes an integrated professional development proposal designed to address the needs identified in the diagnostic phase and to support sustainable teacher training processes within increasingly complex digital ecosystems.

The design of this model assumes that the digital transformation of education cannot be addressed through isolated training initiatives focused exclusively on the acquisition of technical or practical competences. On the contrary, it requires professional development models capable of fostering a critical understanding of technologies, their meaningful integration into teaching, and teachers' ability to innovate within their own professional contexts. From this perspective, the artefact developed seeks to bring together conceptual knowledge, pedagogical experimentation, critical reflection and participation in professional learning communities.

Therefore, the artefact developed is organised around a multi-level architecture designed to support teachers through different stages of professional development. This architecture includes progressive levels of emerging digital competence, pedagogical integration and educational innovation, enabling teachers to progress from an initial understanding of emerging technologies to more sophisticated forms of pedagogical use and the transformation of their practices. At the same time, it incorporates different learning formats, including microlearning experiences, MOOCs and communities of practice, designed to meet the demands for flexibility, personalisation and lifelong learning that characterise today's professional contexts.

One of the distinctive features of this framework lies in its ecological orientation. Rather than viewing digital competences as exclusively individual attributes, the model assumes that they emerge from the interactions between teachers, technologies, resources, institutional cultures and educational contexts. Thus, professional development is understood not as a linear process of acquiring competences but as a continuous journey of adaptation, participation and innovation within constantly evolving educational ecosystems.

Within the framework of Design-Based Research, this model constitutes both a solution to an empirically identified educational problem and a research object that can be tested, refined and validated through successive cycles of implementation. Consequently, the artefact presented in this study should not be understood as a finished product but as an initial version that is theoretically grounded and empirically supported, which will serve as the basis for future phases of experimentation and evaluation within the research. It is precisely the results of these future implementations that will enable the validation, adjustment and refinement of the design principles now proposed, contributing to the progressive development of knowledge regarding sustainable models of professional development for teachers in digital education.

Thus, the main contribution of this phase of the research lies not only in the design of specific training programmes but, above all, in the creation of a conceptual and operational model that integrates assessment, professional development and pedagogical innovation within a coherent framework of sustained educational transformation. It is in this sense that the artefact produced has both practical value, as a proposal for intervention, and scientific value, as an object of research and a source of new design principles for the continuing professional development of teachers.

4. Results

The results presented in this section relate to the educational artefact developed during the design phase of the research. Although its design was directly informed by the results of diagnostic studies carried out in Portugal and Brazil, they should not be interpreted as empirical findings from implementation or evaluation. The focus of this section is therefore on describing the characteristics of the model devised and explaining how the evidence gathered guided the design decisions underpinning its architecture, its learning pathways and its pedagogical principles.

4.1. Design of the Professional Development Model

The results obtained during the project's diagnostic phase revealed consistent patterns between the Portuguese and Brazilian contexts, particularly regarding emerging competences associated with Artificial Intelligence, Online Education and Open Education. The convergence of results observed in both countries made it possible to identify a set of cross-cutting training needs that transcend national specificities and reflect broader transformations in contemporary educational ecosystems.

Based on this evidence, a model for continuous professional development was devised, aimed at training teachers in the emerging areas included in the Pedagogical DigCompEdu Reloaded framework. The model adopts an ecological perspective on digital education, viewing the development of pedagogical-digital competences as a dynamic process that emerges from the interaction between teachers, technologies, institutional contexts and communities of practice.

Unlike approaches centred on the transmission of technological knowledge or on instrumental training, the proposed model seeks to promote flexible, sustainable learning pathways geared towards the transformation of pedagogical practices. In this regard, its conception was guided by five design principles that emerged from the interplay be-

tween the empirical findings of the diagnostic phase, the literature on teacher professional development and the conceptual framework of Pedagogical DigCompEdu Reloaded.

Table 2 is presented to clarify the relationship between the results obtained from the diagnostic studies and the adopted design choices.

Table 2. Relationship between empirical evidence and design decisions.

Empirical Evidence	Identified Need	Model Response
Very low proficiency in AI	Development of literacy skills and the pedagogical integration of AI	Artificial Intelligence pathway
Weaknesses in online education	Development of online design, communication and assessment skills	Online Education pathway
Low proficiency in Open Education	Development of open educational practices	Open Education pathway
Need for continuous updating	Flexible and modular training	Microlearning
Need for scalable access	Large-scale open training	MOOCs
Need for ongoing support for change	Collaborative learning	Communities of practice

Beyond the general correspondences presented in Table 1, the diagnostic findings directly informed several design decisions within the model. The high concentration of teachers at the initial proficiency levels (A1 and A2), particularly in Artificial Intelligence, Open Education and Online Education, led to the definition of progressive learning objectives organised around three levels of development: emerging digital literacy, pedagogical integration and pedagogical innovation. This structure was intended to support a gradual progression from conceptual understanding to pedagogical application and, subsequently, to educational transformation.

The specific competences selected for each pathway were derived from the areas in which the lowest levels of proficiency were identified, including AI-supported assessment, the pedagogical use of generative AI, online learning design, digital communication, open educational resources and open pedagogical practices.

The pedagogical principles adopted in the model were likewise informed by the empirical evidence. The need for continuous updating in rapidly evolving domains supported the integration of microlearning strategies; the need for broad and scalable access to professional development justified the use of MOOCs; and the need for sustained support during pedagogical change processes led to the incorporation of communities of practice. Furthermore, assessment mechanisms were designed to prioritise authentic demonstrations of competence through projects, portfolios, educational resources and practice-based activities, thereby ensuring coherence between identified needs, expected learning outcomes and professional development practices.

4.2. Design Principles of the Model

The first principle—Competence-Driven Design—states that professional development should be directly guided by teachers' actual needs and the competences they need to develop. The results of the diagnostic phase revealed significant differences across areas of competence, demonstrating that teachers do not have uniform needs. Consequently, training should not be designed based on a uniform and undifferentiated approach but structured according to the specific identified competences.

From this perspective, the Pedagogical DigCompEdu Reloaded framework serves simultaneously as a diagnostic tool and as a guiding structure for professional development. Each training programme has been designed to address specific sets of competences related

to open education, online education and the pedagogical integration of artificial intelligence, enabling a direct alignment between identified needs and learning opportunities.

The second principle—Microlearning Flexibility—recognises the need to develop training models compatible with teachers' actual working conditions. The growing complexity of teaching roles and limited time availability require training formats that are flexible, accessible and adaptable to different learning paces.

In this context, the model prioritises microlearning strategies, organised into short, self-contained units geared towards specific learning objectives. These micro-learning experiences enable teachers to build personalised professional development pathways, reconciling the demands of continuing professional development with the challenges of day-to-day practice.

Microlearning also emerges as a promising strategy for promoting processes of continuous updating in areas characterised by rapid technological evolution, such as generative artificial intelligence and new forms of networked digital education.

The third principle—Open Educational Practices—stems directly from the incorporation of Open Education as one of the central dimensions of the Pedagogical DigCompEdu Reloaded framework. The results of the assessment revealed low levels of proficiency in competences related to the use of Open Educational Resources, knowledge sharing and the development of open educational practices.

Consequently, the training model treats openness as a structuring principle rather than merely as a curricular content area. The aim is for teachers to develop the competences to locate, adapt, produce and share open educational resources, as well as to participate in collaborative knowledge-building communities.

Openness is seen as an essential condition for promoting the democratisation of access to knowledge, pedagogical innovation and the sustainability of professional development processes, enabling the products and resources generated within the context of training to be reused, adapted and disseminated in different educational contexts.

The fourth principle—Practice-Based Experimentation—is based on the idea that effective professional development occurs when teachers have the opportunity to experiment with, apply and reflect on new pedagogical approaches in authentic contexts.

From this perspective, the model moves away from transmissive approaches to training and prioritises methodologies centred on problem-solving, the design of activities and the implementation of innovative pedagogical experiences. Participants are encouraged to develop context-specific projects, test teaching strategies supported by digital technologies and critically analyse the results obtained.

Experimentation is understood as an essential mechanism for promoting the transfer of acquired knowledge into educational practice, whilst simultaneously fostering the construction of situated and relevant professional knowledge.

The final principle—Reflective and Ethical Use of AI—stems from the growing presence of artificial intelligence in educational contexts and the weaknesses identified in the field of its pedagogical integration.

Whilst artificial intelligence offers new possibilities for personalising learning, producing educational resources, assessment and supporting pedagogical decision-making, its use also raises ethical challenges relating to transparency, privacy, intellectual property, algorithmic biases and student autonomy.

Consequently, the proposed model seeks to move beyond approaches focused solely on the instrumental learning of digital tools, by promoting a critical understanding of the role of artificial intelligence in educational processes. Teacher training should include not only technical competences but also ethical, reflective and pedagogical competences that enable the responsible use of these technologies for the benefit of learning.

4.3. Model Architecture

Based on the principles outlined above, a professional development architecture was designed, organised into three progressive levels of complexity. This structure aims to support gradual processes of developing pedagogical-digital competences, enabling teachers to progress from an initial understanding of emerging domains to more sophisticated forms of pedagogical innovation.

The model's architecture is organised into a progressive framework for professional development comprising three interlinked levels. Each level corresponds to an increasing degree of mastery, integration and transformation of digital teaching practices, all of which are underpinned by a set of cross-cutting dimensions that ensure the continuity and sustainability of teachers' professional development.

The architecture presented in this study should be understood as a conceptual and pedagogical model rather than as a formal computational or mathematical model. Accordingly, the relationships between domains, learning pathways, progression levels and pedagogical components are defined through theoretically grounded educational principles and empirically informed design decisions. The structure of the model specifies the role and function of each component within the professional development architecture while retaining the flexibility required for adaptation to different educational contexts. This approach is consistent with design-oriented research in education, where conceptual coherence, pedagogical alignment and empirical grounding constitute essential criteria for model development and validation.

As shown in Table 3, the model assumes a gradual progression from the development of emerging digital competences to pedagogical innovation, underpinned by flexible strategies for continuing professional development and by collaborative mechanisms for building and sharing professional knowledge.

Table 3. Multilevel structure of the model.

	Level 1	**Level 2**	**Level 3**
Designation	Emerging Digital Literacy	Pedagogical Integration	Pedagogical Innovation
Focus	Adoption	Application	Transformation
Role of the teacher	Informed user	Designer of learning experiences	Agent of innovation
Expected outcome	Development of emerging competences	Pedagogical integration of technologies	Transformation of educational practices

The first level—Emerging Digital Competence—corresponds to the foundational stage of the model and has as its main objective the promotion of a conceptual understanding of the emerging areas integrated into the Pedagogical DigCompEdu Reloaded framework.

At this level, training programmes focus on the development of competences related to Artificial Intelligence, Online Education and Open Education. Teachers are encouraged to understand fundamental concepts, identify the potential and limitations of emerging technologies, and explore their impacts on teaching and learning processes.

The training predominantly takes the form of microlearning and introductory courses, prioritising short-duration, highly flexible experiences.

The second level—Pedagogical Integration—aims to support teachers in the transition from conceptual knowledge to the pedagogical application of the developed competences.

The focus shifts from understanding the principles to the design of educational strategies, learning activities, online communication processes, open educational practices and the pedagogical use of artificial intelligence.

At this level, participants engage in pedagogical design experiences, developing contextualised resources, activities and learning scenarios. The predominant formats include modular courses, online workshops and specialised MOOCs, accompanied by activities involving experimentation and reflection on practice.

The third level—Pedagogical Innovation—represents the most advanced phase of the model and focuses on the transformation of educational practices.

At this stage, teachers are encouraged to act as agents of innovation, developing integrated pedagogical projects that combine Artificial Intelligence, Online Education and Open Education to create new learning ecosystems.

The training prioritises collaborative approaches and intervention projects in real-world contexts, with the aim being not merely the competent use of digital technologies but the ability to design innovative, sustainable and pedagogically meaningful educational experiences.

In summary, the model's architecture can be represented as a progression across three complementary levels: Foundation: Emerging Digital Competence; Development: Pedagogical Integration; and Transformation: Pedagogical Innovation.

This progression reflects a developmental journey that begins with the development of conceptual understanding, moves on to the pedagogical integration of emerging competences, and culminates in the ability to innovate and transform educational practices, contributing to the creation of more open, networked learning ecosystems underpinned by a critical and responsible use of digital technologies.

4.4. Professional Development Pathways: Training Pathways

Based on the results obtained during the diagnostic phase and the design principles outlined above, a professional development model was devised, organised into three complementary thematic pathways corresponding to the emerging areas of the Pedagogical DigCompEdu Reloaded framework: Artificial Intelligence, Online Education and Open Education. These pathways are structured to respond directly to the needs identified amongst Portuguese and Brazilian teachers and seek to promote the gradual and sustainable development of pedagogical-digital competences.

The organisation of the pathways is based on a progressive approach that combines different formats of lifelong learning. Rather than offering isolated training activities, the model seeks to create a cohesive ecosystem of training opportunities, enabling teachers to build personalised pathways according to their interests, needs and levels of proficiency. Each pathway incorporates microlearning activities and MOOCs, promoting flexibility, scalability and sustainability in professional development.

Pathway A, dedicated to Artificial Intelligence in Education, seeks to address the weaknesses identified in the pedagogical integration of AI, one of the areas where studies have revealed lower levels of proficiency. Its main objective is to enable teachers to critically understand how artificial intelligence technologies work, explore their pedagogical potential and develop practices for their ethical and responsible use.

In addition to developing competences related to the integration of artificial intelligence, this programme incorporates an ethical and critical dimension centred on the protection of personal data, privacy, intellectual property, algorithmic transparency, the responsible use of generative systems, the identification of biases, and human oversight of AI-supported processes.

The pathway begins with a micro-credential focused on the fundamentals of artificial intelligence for teachers, covering essential concepts, the operating principles of intelligent systems, the transformative potential of AI in educational ecosystems, and the main ethical challenges associated with its use. Next, a second micro-credential is dedicated to

developing competences related to prompt engineering and the creation of educational content supported by generative artificial intelligence, enabling teachers to understand how these technologies can support pedagogical planning, the production of resources and the facilitation of learning experiences. The third micro-credential focuses on the integration of AI into teaching, learning and assessment processes, exploring aspects relating to personalised learning, automated feedback, AI-assisted assessment and the potential of learning analytics systems.

As a unifying element of the programme, a MOOC dedicated to educational innovation using artificial intelligence is proposed, structured around topics such as AI competence, the design of teaching activities, AI-assisted assessment, algorithmic ethics and the creation of personalised learning experiences. This MOOC aims to offer an integrated view of the pedagogical possibilities of artificial intelligence and to create a broad community for learning and knowledge-sharing amongst teachers.

The aim is thus to promote what Selwyn (2019) refers to as a critical approach to artificial intelligence in education, capable of balancing technological innovation and pedagogical reflection.

Pathway B focuses on competences related to online and network-based education, a field that has taken on particular relevance following the intensified processes of digital transformation in recent years. The results obtained during the diagnostic phase highlighted significant weaknesses in the creation of online activities, the management of online communication, the facilitation of virtual communities and assessment in virtual environments.

In this context, the programme begins with a micro-credential dedicated to digital learning ecosystems, aiming to support teachers in understanding the characteristics of virtual learning environments, synchronous and asynchronous communication processes, and the development of pedagogical presence in digital contexts. A second micro-credential focuses on pedagogical design in online environments, emphasising the creation of e-activities, collaborative learning strategies, and methodologies and models for networked learning. The third micro-credential is specifically dedicated to online assessment processes, exploring digital feedback strategies, the use of rubrics, formative assessment practices, and mechanisms for self-assessment and peer assessment.

The programme culminates in a MOOC on Online Education and Networked Learning, designed to explore concepts related to digital ecosystems, collaborative learning, online assessment, the building of virtual learning communities, and the design of educational experiences in hybrid and digital environments.

Inspired by the perspectives of connective learning and networked pedagogies, the programme aims to equip teachers to design virtual environments that promote participation, interaction and the collaborative construction of knowledge (Siemens, 2005; Downes, 2012).

Pathway C focuses on Open Education, a field which, despite its growing international significance, continues to show relatively low levels of uptake amongst teachers. The findings of the assessment revealed significant weaknesses relating to the use of Open Educational Resources, knowledge of open licences, and the implementation of teaching practices based on the principles of openness and participation.

The pathway begins with a micro-credential dedicated to the fundamentals of Open Education, covering its principles, conceptual evolution, democratising potential and significance within today's digital learning ecosystems. The second micro-credential focuses on Open Educational Resources, exploring aspects related to the 5R principles, Creative Commons licences, the selection and adaptation of resources, and the collaborative production of educational content. The third micro-credential is dedicated to open pedagogical practices, encouraging the development of competences related to participation in collaborative

networks, co-authorship, the collective construction of knowledge, and the promotion of more inclusive and participatory forms of learning.

In addition, a MOOC on Open Education and Open Pedagogical Practices is proposed, designed to explore the theoretical and methodological foundations of this paradigm in greater depth and to support teachers in designing open and collaborative educational experiences. This approach is in line with the proposals of Wiley and Hilton (2018), Cronin (2017) and Inamorato dos Santos (2019), who advocate a broader understanding of Open Education, not limited to resources but also encompassing cultures and pedagogical practices of openness.

4.5. Professional Development Formats of the Model

One of the central aspects of the proposed model lies in the diversity of the learning formats made available. This approach seeks to address the need to create professional development pathways that are flexible, adaptable and compatible with the different contexts in which the teaching profession is practised.

The model is based on microlearning experiences, organised into micro-credentials, designed as certified professional development units focused on specific competences. Each micro-credential incorporates learning activities; opportunities for practical experimentation; and assessment mechanisms based on the demonstration of competence, such as digital portfolios, projects or educational resources produced by the participants. These training courses enable a more in-depth development of the identified competences as priorities within the Pedagogical DigCompEdu Reloaded framework.

The second level consists of MOOCs (Massive Open Online Courses) designed to provide an integrated and in-depth overview of each of the emerging areas. MOOCs play a strategic role in the scalability of the model, enabling it to reach a wide number of participants and promoting the creation of learning networks amongst teachers from different geographical and institutional contexts.

Finally, across all pathways, the model provides for the creation of communities of practice, understood as permanent spaces for collaboration, sharing and collective professional development. These communities act as mechanisms to sustain the learning achieved throughout the training pathways, fostering the exchange of experiences, reflection on teaching practices and the collaborative construction of knowledge.

As such, the proposed model constitutes a genuine ecosystem for teachers' professional development, bringing together different training approaches and meeting contemporary demands for flexibility, personalisation, openness and continuous learning. The integration of microlearning, MOOCs and communities of practice seeks to ensure not only the acquisition of emerging competences but also their transfer into teaching practice and their consolidation over time, contributing to a sustainable transformation of educational ecosystems.

5. Discussion

The results obtained from studies carried out in Portugal and Brazil reveal a pattern that is particularly relevant for understanding the current challenges of the digital transformation of education. Whilst a relatively well-established level of proficiency is observed in the pedagogical-digital competences traditionally associated with DigCompEdu, significant weaknesses are evident in the emerging competences related to Online Education, Open Education and Artificial Intelligence. In both contexts, these three areas show substantially lower levels of adoption, highlighting difficulties in creating online learning activities, adopting open educational practices and integrating artificial intelligence into teaching.

These findings support a key initial argument: it is not enough to assess digital competences; it is also necessary to design professional development ecosystems capable of addressing the identified needs. Over the last decade, much of the research into teachers' digital competences has focused on the development of frameworks, assessment tools and diagnostic studies. Whilst this knowledge is indispensable for understanding the current state of development of teachers' digital competences, the mere identification of gaps does not, alone, bring about educational transformation. As argued in work carried out within the framework of Design-Based Research, the relevance of educational research lies in its ability to convert empirical evidence into solutions capable of improving educational practice in authentic contexts.

In this sense, the main contribution of this study lies precisely in shifting the focus from evaluation to design. Rather than treating diagnosis as an end, it is assumed that the results should serve as the starting point for the development of sustained, contextualised professional development processes geared towards transforming teaching practices.

The proposed model seeks to address this challenge by creating professional development pathways directly aligned with the emerging competences identified in the Pedagogical DigCompEdu Reloaded framework, establishing an explicit link between empirical evidence, pedagogical design and teachers' professional development.

A second particularly relevant aspect concerns the convergence of the results obtained in the two national contexts. Despite the cultural, organisational and political differences between Portugal and Brazil, the assessments carried out revealed very similar trends regarding emerging competences. This finding suggests that the identified challenges do not stem exclusively from the specific characteristics of a particular education system but reflect broader transformations associated with the emergence of new digital learning ecosystems. The difficulties relating to the pedagogical use of Artificial Intelligence, the creation of online educational experiences and the adoption of open practices appear to be challenges shared by teachers working in different educational contexts, appear to constitute recurring challenges across the educational contexts examined in this study.

This interpretation aligns with ecological perspectives on digital education, which view teaching competences not as isolated individual attributes but as capacities that emerge from the interaction between individuals, technologies, organisations, institutional cultures and learning contexts. From this perspective, the fragility observed in emerging competences should not be interpreted as an individual shortcoming on the part of teachers but as a reflection of the speed at which educational ecosystems are being reconfigured by the expansion of artificial intelligence, the consolidation of digital environments and the growing emphasis on the philosophy of openness in education.

The findings also suggest that traditional models of continuing professional development may prove insufficient to address the complexity of these challenges. Conventional formats, often based on one-off, decontextualised activities, tend to prioritise the transmission of content or the instrumental and technical learning of technology. However, the nature of the competences identified in this study requires training approaches that are more flexible, long-term and integrated into teachers' professional practices. The development of competences related to artificial intelligence, online education or open practices involves ongoing processes of experimentation, reflection, adaptation and reconstruction of pedagogical practices.

In this context, the proposed model is based on the idea that teachers' professional development should be understood as a continuous, modular and open-ended process: continuous because technological and pedagogical changes demand constant updating and lifelong learning; modular because teachers have differing needs and varying levels of proficiency, making it necessary to design flexible and customisable pathways; and open

because the very nature of emerging competences requires cultures of sharing, collaboration and the collective construction of knowledge.

The integration of complementary formats, such as microlearning, MOOCs and communities of practice, seeks precisely to address this reality. Whilst micro-credentials promote the development of specific competences, MOOCs ensure scalability and widespread access, and communities of practice guarantee the continuity of learning beyond formal training sessions. This training architecture aligns with an ecological conception of professional development, in which learning emerges from the ongoing interaction between people, resources, contexts and knowledge networks.

It is also important to emphasise that the presented model is not intended to be a definitive or universal solution. In line with the principles of Design-Based Research, the model should be understood as an initial conceptual artefact, developed based on an analysis of the identified needs and intended to be subsequently implemented, evaluated and refined in real-world contexts. Its main contribution therefore lies in the formulation of design principles for teachers' professional development within emerging digital ecosystems, contributing to the international debate on how to support teachers in the critical, ethical and pedagogically meaningful integration of Artificial Intelligence, Online Education and Open Education.

Although this article focuses exclusively on the design phase, the project envisages continuing the Design-Based Research cycle through the implementation and evaluation of the devised training programmes.

The subsequent stages will involve testing the training models in real educational contexts, collecting quantitative and qualitative data on their use, analysing their impact on participants' digital competences and teaching practices, and progressively refining the models developed. In parallel, it is hoped that increasingly robust design principles will be produced, which can be transferred to other educational contexts.

As such, this study should be understood as the design phase of a broader process of educational research and innovation, the aim of which is to develop a model for teachers' professional development in the emerging fields of Artificial Intelligence, Online Education and Open Education. Rather than simply proposing a set of training courses, the aim is to contribute to the development of a professional learning ecosystem capable of supporting teachers in developing critical, reflective and transformative teaching practices suited to the demands of today's digital educational environments.

6. Conclusions

The rapid evolution of digital learning ecosystems is profoundly transforming the nature of teaching and the way in which teachers interact with contemporary educational environments. In this context, the development of pedagogical-digital competences is an essential prerequisite for teachers to participate in educational innovation processes in a critical, creative and pedagogically grounded manner. The results of studies carried out in Portugal and Brazil have shown that, although there is already a relatively well-established level of competences associated with the traditional areas of DigCompEdu, significant weaknesses persist in the emerging domains of Online Education, Open Education and Artificial Intelligence (Moreira et al., 2025).

The convergence of the findings from the two countries suggests that the challenges associated with the development of pedagogical and digital competences stem from broader structural transformations linked to the digitalisation of education, the emergence of cognitive technologies, and new forms of knowledge production and circulation. These findings reinforce the need for sustainable training solutions that can be adapted to different educa-

tional contexts. Thus, the data point to the existence of systemic challenges that require equally systemic and sustainable responses (Dias-Trindade et al., 2025).

Building on this evidence, this study sought to move beyond an exclusively diagnostic approach to teachers' digital competences, proposing a model of professional development designed to address the needs identified in studies carried out in Portugal and Brazil.

The proposed professional development model seeks to address this challenge by creating training pathways organised around three strategic areas identified by Pedagogical DigCompEdu Reloaded as particularly critical for contemporary teaching: Online Education, Open Education and Artificial Intelligence. Inspired by the principles of Design-Based Research and grounded in an ecological perspective on digital education, the model conceives of professional development as a continuous process of participation, experimentation, reflection and the reconstruction of practice.

The proposed model is based on an integrated framework comprising microlearning, MOOCs and communities of practice, aiming to provide flexible opportunities for lifelong learning that are tailored to the diverse needs of teachers and aligned with contemporary approaches to sustainable professional development that value personalisation, modularity, openness and networked learning as essential conditions for educational innovation (Desimone, 2009; Opfer & Pedder, 2011; Darling-Hammond et al., 2017).

It is important, however, to recognise that the model presented here is still a preliminary design artefact developed as part of the second phase of the project. In line with the principles of Design-Based Research, the next research cycles should focus on implementing the training pathways with teachers, evaluating their impact on teaching practices, and progressively refining the design principles initially formulated. It is precisely through these iterative cycles of implementation, analysis and redesign that it will be possible to generate more robust knowledge about the processes of teachers' professional development within emerging digital ecosystems.

It is important to emphasise that the model presented is still a design artefact whose effectiveness has not been empirically evaluated within the scope of this study. Consequently, the contributions identified should be understood as theoretically and empirically grounded possibilities that require validation through the future implementation and evaluation phases envisaged in the Design-Based Research cycle.

Although the model was designed to promote the transfer, consolidation and long-term sustainability of teachers' pedagogical-digital competences, these outcomes remain prospective and have not yet been empirically validated. At this stage, the study presents a theoretically and empirically informed design proposal whose potential contribution lies in its capacity to support coherent and sustained professional development pathways. Evidence regarding its effectiveness, impact on teaching practices and sustainability over time will depend on future implementation and evaluation studies.

In summary, this study supports the idea that the real challenge of the digital transformation of education no longer lies solely in measuring digital competences but in designing sustainable professional development ecosystems capable of supporting teachers in the critical, ethical and pedagogically meaningful integration of Online Education, Open Education and Artificial Intelligence. It is precisely in this shift from diagnosis to design and from assessment to transformation that the main scientific contribution of this work lies.

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