effecTive

WORK PACKAGE
01

EVIDENCE-BASED PRINCIPLES FOR EFFECTIVE TEACHER TRAINING OF PEDAGOGICAL DIGITAL COMPETENCE (PDC)

DELIVERABLE D1.2

Work Package 1

Theoretical foundation and policies of effective teacher PDC training to support student learning

Deliverable D1.2

Evidence-Based Principles for Effective Teacher Training of Pedagogical Digital Competence (PDC)

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Executive summary

Deliverable 1.2 within the EffecTive project addresses strategies for enhancing teachers' Pedagogical Digital Competence (PDC) through effective training interventions. PDC is defined as a blend of technological, pedagogical, and content knowledge, coupled with teachers' situational skills, attitudes, and motivations for digital integration in classrooms. The goal of this deliverable is to analyse the core components of effective teacher training interventions that impact PDC, exploring their influence on teachers' instructional practices and student learning outcomes. Key insights from the review are structured around five central themes in line with research questions:

1. **Characteristics of PDC training interventions**: The review found that effective PDC interventions vary in structure, duration, and mode, often integrating online, blended, and face-to-face formats. Blended models emerged as particularly effective, providing both flexibility and in-person interaction. Pre-service teachers often benefit more from these interventions than in-service teachers, possibly due to their developmental stage.
2. **Training methods and practices**: Reflection, hands-on learning, practice lesson planning, and rehearsal/field experience were identified as the most frequently employed practices. Combining multiple training strategies (e.g., reflection and mentoring) appears to enhance teachers' practical skills and confidence in technology integration. Direct evidence on the comparative effectiveness of individual practices remains limited, though.
3. **Effects on teachers' knowledge and motivation**: PDC training interventions generally improved teachers' knowledge in technology, pedagogy, and content, although technological knowledge (TK) remains challenging to develop. Longer interventions with collaborative elements and blended learning modes yielded stronger results, particularly for pre-service teachers.
4. **Impact on classroom practices**: Training interventions positively influenced

teachers' ability to integrate technology in ways that enhance student engagement and promote dynamic, student-centered learning environments. Practical, hands-on approaches fostered confidence and positive attitudes, essential for effective classroom application.

5. **Impact on student outcomes**: Although evidence on student outcomes was limited, some studies reported benefits such as higher engagement and specific gains in academic skills like reading and mathematics. Results varied, underscoring the importance of contextual factors in intervention success.

Implications for practice

Effective teacher training should employ a blend of reflective, practical, and collaborative practices to maximise impact. Blended learning formats provide an optimal structure for achieving engagement and practical skill development. Addressing affective factors - like self-efficacy and attitudes toward technology - alongside instructional knowledge is essential for effective implementation. Additionally, focusing on long-term, collaborative interventions can enhance the development of PDC, particularly in pre-service teacher education.

Limitations and future directions

This review highlights limitations, including variability among study designs and a lack of detailed comparative analyses on training methods. Selection bias and limited generalisability also warrant caution. Future research should investigate the relative effectiveness of specific training elements and emphasise long-term impacts on both teachers and students. Expanding research to examine how PDC training interventions impact diverse classroom contexts will further strengthen these findings.

In conclusion, Deliverable 1.2 provides evidence-based insights into the design of effective PDC training interventions, advocating for integrated, blended approaches that combine practical skills and positive attitudes to support technology integration in teaching.

1 Introduction

EffecTive, as part of the Horizon Europe framework programme, undertakes a Research and Innovation Action with the primary goal of enhancing **teachers' Pedagogical Digital Competence (PDC)**. Teachers' PDC in the EffecTive Project is defined as a synergy of teachers' technological, pedagogical, and content knowledge, their intersections, affective-motivational dispositions regarding technology integration in the classroom, their situation-specific skills (perception, interpretation, and decision-making), their cultural awareness and abilities to promote equity in a specific learning situation (Blömeke et al., 2015; Roth et al., 2023; Skantz-Åberg et al., 2022).

The project is dedicated to identifying the key factors that can support teachers' PDC, considering the conditions' effectiveness and efficiency. We define **effectiveness** as a positive impact of the training on the quality of education (improved teachers' PDC, students' learning outcomes, inclusive learning environment). We define **(cost) efficiency** as the best way to transform costs into benefits. Our approach involves **developing a comprehensive methodology to assess the impact of various PDC training programmes for teachers.** The evaluation focuses on how these training programmes influence teachers' pedagogical digital competence, their instructional methods, and the subsequent effect on student learning outcomes. All this requires a wide range of data to be collected from students and teachers to evaluate the experience, effectiveness, and efficiency of the training. Intervention studies will be designed and conducted in two sub-phases. The first phase (starting Month 4) is used for piloting newly developed modules or materials as well as research instruments while in the second phase, at least 12 intervention studies in five countries will be implemented.

One of the main objectives of EffecTive is to gather evidence and improve the knowledge of important **factors that influence the effectiveness and efficiency of teacher training approaches to transform teacher professional development and student learning.** We will also develop a knowledge base of effective training approaches to ensure an efficient use of public resources to develop teacher PDC and improve learning outcomes.

The aim of Deliverable 1.2 is **to analyse different elements of effective teacher training interventions and their effects on teachers' pedagogical digital competence (PDC) and students' learning**. The analytical framework is based on prior research identifying key components that make teacher training effective. **Section 1** acts as an introduction, outlining the scope and objectives of this deliverable. In **Section 2** of the Deliverable, we present a summary of the theoretical framework of Effective, which has been further elaborated in our D1.1 (Zabolotna et al, 2024). **Section 3** introduces the main research questions for our literature review. We provide an overview of the methodological procedure of the literature review, including inclusion and exclusion criteria for literature selection, literature search, and an overview of the included papers in **Section 4**. While **Section 5** presents the results corresponding to each of the research questions, **Section 6** offers discussion of these findings in connection with the related literature, highlighting the strengths and limitations of the current umbrella review. Finally, in **Section 7,** we conclude with the key findings and implications for practice and future research.

2 Theoretical Framework

2.1 Teachers' Pedagogical Digital Competence

The general assumption of EffecTive is that the quality of education and learning can be increased by improving teachers' PDC. Based on Roth et al. (2023), we have adapted a competence framework that is grounded in previously developed and well-established models, such as the PID model (Blömeke et al., 2015) and the TPACK model (Mishra & Koehler, 2006). The PID (Perception, Interpretation, Decision-Making) model focuses on cognitive processes and outlines how individuals perceive information, interpret their significance, and make decisions based on that interpretation.

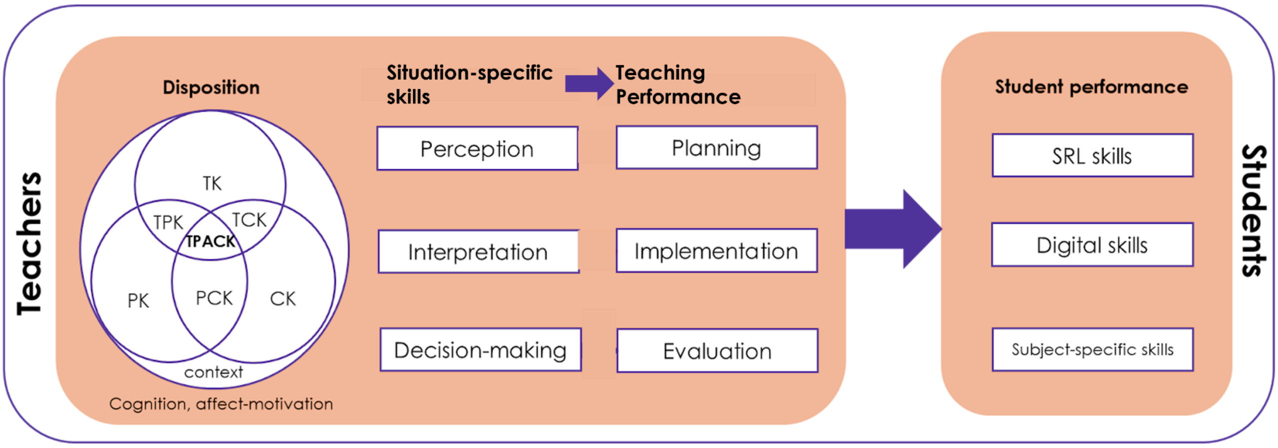

Figure 1. Competence Framework for Teachers' PDC (adapted from Roth et al., 2023)

In this framework, teachers' competencies are viewed as a continuum from **dispositions** or traits (cognitive, affective, and motivational) that underlie **situation-specific skills** (perception, interpretation, and decision-making) and, in turn, result in **observed behaviours** (performance) in a particular classroom situation leading to changes in students' learning (Blömeke et al., 2015).

Dispositions, according to the TPACK model, include three important knowledge domains of teachers - **content knowledge (CK), pedagogical knowledge (PK) and technological knowledge (TK) - and their intersections**. Teachers' technological pedagogical content knowledge (TPCK) is represented at the centre of the model and refers to teachers' knowledge of how to successfully integrate educational technologies using appropriate pedagogical methods for their subject matter (Mishra & Koehler, 2006). Complementing the cognitive dispositions, **affective and motivational traits** such as teachers' self-efficacy beliefs, their attitudes towards digital technologies, and their self-perceived confidence and readiness for technology integration are considered crucial for the effective development of teachers' PDC (Knezek & Christensen, 2016; Hagenauer et al., 2023). In the context of PDC, **self-efficacy** is about how teachers perceive their individual ability to integrate digital tools into their teaching practices in a way that promotes meaningful instruction with the application of digital tools appropriate for a specific situation (Ertmer, 2005; Holden & Rada, 2011; Spencer, 2016). Closely linked to self-efficacy beliefs are teachers' **attitudes** toward and confidence in using digital technology in the classroom. Attitudes rely on combined beliefs about a specific object or situation (Instefjord & Munthe, 2017) and are interconnected with one's **confidence** to apply certain skills in such a situation. Together, attitudes and confidence are significant predictors of whether and how teachers use technology in their practice. For example, teachers who are already proficient ICT users and apply digital tools in teaching are more motivated to extend their use and improve their skills (Ertmer et al., 2012; Pongsakdi et al., 2021).

Teachers' situation-specific skills have also been researched under the terms "professional vision" or "professional noticing", emphasising their ability to observe and respond adeptly to classroom interactions (Stahnke & Blömeke, 2021). The cognitive and affective-motivational dispositions discussed above serve as the underlying traits of teachers' situation-specific skills (Blömeke et al., 2015), especially in **perception, interpretation, and decision-making.** These, in turn, influence teachers' behaviours in specific classroom settings. Perception involves the initial recognition of elements in a situation whereas interpretation requires analysing this information to understand its implications, and decision-making involves choosing actions based on this understanding (Blömeke et al., 2015). In the context of our project, we assume that while developing lesson plans or planning pedagogical practices with the integration of digital tools, teachers must foresee different situations and identify appropriate courses of action.

Teachers' situation-specific skills are essential prerequisites for **teachers' performance,** i.e. their observable behaviour, which is manifested in the planning, implementation and evaluation of teaching (Roth et al., 2023). Teachers' dispositions may transform into performance due to teachers' individual perceptions and interpretations of a specific classroom situation as well as decision-making (Blömeke et al., 2015). Therefore, our focus in the EffecTive project extends to **the interaction between teachers' situation-specific skills and their actual performance**. These practical skills are built upon teachers' dispositions and refined through their situation-specific skills, which are essential prerequisites for their performance and, mediated through their teaching actions, leading to improved students' learning and performance (Roth et al., 2023).

Student performance can be categorised as **subject-specific skills** (e.g., mathematical achievement) and **general competencies** (also known as transversal or 21st-century skills). In EffecTive, students' performance is specifically focused on three main components: **(1) subject-specific skills; (2) self-regulated learning (SRL) skills; and (3) digital competence**. Based on the majority of the current assessment approaches in compulsory education, students' subject-specific skills are the foundation of academic achievement . These skills encompass deep knowledge and understanding of core concepts, the ability to apply this knowledge to solve problems, and proficiency in subject-specific techniques and methods. For instance, strong maths skills involve not only memorising formulas but also being able to analyse data, construct logical arguments, and solve equations (Cresswell & Spilman, 2020). While a strong foundation in subject-specific skills is crucial, effective use of technology in education also requires students to develop their **SRL** skills due to increased autonomy and the dynamic nature of the learning process (Seufert, 2018). According to Zimmerman (2000), self-regulation refers to "self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals" (p. 14). In ~~its~~ turn, self-regulated learning refers to a multi-component, iterative, self-directed process that involves not only learners goal orientation but also the generation of thoughts, feelings, and actions as well as the systematic work towards the set (learning) goals (Boekaerts, 2002; Boekaerts & Cascallar, 2006). The final component of student performance is their **digital competence**. It extends beyond just using technology but involves the ability to develop domain-specific digital skills and leverage them for effective problem-solving (OECD, 2020).

2.2 Effective Teacher Training

In the literature, it is widely assumed that teacher training is effective if it results in changes in teachers' practices and improvements in student learning outcomes (e.g., Basma &

Savage, 2018; Darling-Hammond et al., 2017). This assumption is based on a framework for evaluating training programmes developed by **Kirkpatrick (1959**). The framework defines increasing levels of training effectiveness, consisting of (1) **participants' satisfaction**, (2) **changes in their knowledge and beliefs**, (3) **changes in their practices**, and (4) r**esults of their changed professional behaviour at the organisational leve**l (e.g., student outcomes).

In the past 25 years, there has been a significant growth in scholarly efforts to identify **core features** of effective teacher training. Several lists of design principles have emerged, and there seems to be a consensus of 5-7 presumably effective features (Asterhan & Lefstein, 2024). According to Desimone (2009) critical features of teacher training include content focus, active learning, coherence (consistency of school, district, and state policies), duration, and collective participation. This list has been updated by Darling-Hammond et al. (2017), who identified seven characteristics of effective teacher training:

- It is content-focused.
- It includes active learning and is based on adult learning theory.
- It fosters collaboration, usually in job-embedded contexts.
- It uses models and modelling of effective practice.
- It provides coaching and expert support.
- It offers opportunities for feedback and reflection.
- It is of sustained duration.

In a recent rapid review, Cirkony et al. (2024) have come up with eight similar features of effective teacher training: collaboration; active learning and reflection; content and pedagogy in context; sustained duration; coaching; external expertise; models and modelling; audience and alignment.

Although researchers often claim that there is broad consensus about these effective features, **recent research** (e.g., Asterhan & Lefstein, 2024; Sims & Fletcher-Wood, 2021; Sims et al., 2023) **has critiqued the empirical foundations of these lists**. Most empirical studies did not include comparisons of different teacher training features because the design of the teacher training was not the object of investigation. They rather wanted to investigate the effects of teacher training on teacher and student outcomes. To this end, teachers in the treatment group participate in some form of teacher training, while teachers in the control group receive no training. Such studies, however, **provide no evidence on how to best design teacher training.** Studies that did compare different teacher training formats often found no significant differences in teacher and especially student outcomes (Asterhan & Leifstein, 2024). As highlighted by Kennedy (2016), the effectiveness of teacher training not only depends on design elements but also the pedagogy used in the training to facilitate teacher learning and teachers' motivation to learn and change their practice. Other influencing factors include principal/school leader support, individualisation of the training, and teacher buy-in, i.e., whether teachers think the approach has the potential to help their students learn (Desimone, 2023).

Recently, Sims et al. (2023) proposed a new theory of effective teacher professional development, drawing on research from cognitive science, behavioural science, and medical education. The **I/M/T/P framework** defines four purposes of professional development to bring sustained improvements in teaching as well as mechanisms, i.e., activities that are causally responsible for the effects on teaching and learning.

- Instill insight about teaching and learning **(I)**. Example mechanism: Manage cognitive load.
- Motivate change in teachers' practices **(M)**. Example mechanism: Goal setting.
- Develop techniques for the application of insights **(T)**. Example mechanism: Modelling.
- Embed in practice **(P)**. Example mechanism: Prompts/cues.

If teacher training addresses these four purposes, it is likely to be more effective. The list of mechanisms can somehow be regarded as an update of Desimone's (2009) critical features list but with a stronger empirical foundation, i.e., causal evidence from other domains and correlative evidence for the mechanisms and the impact of PD programmes. Future research is still needed to examine the causal relationship between the various mechanisms and teacher development (Sims et al., 2023).

2.3 Training Methods

Years of research in the field of learning sciences have demonstrated that learning naturally occurs in social contexts and is often spread across various people and resources. This same principle also applies to teachers as they learn (Fishman et al., 2014). Putnam and Borko (2000) suggest that teachers' professional learning is more effective when educators can collaboratively learn from one another. To achieve effective training, our project integrates four key training methods, each of which is grounded in educational theories and incorporates diverse social learning mediators. These training methods are: Knowledge Instruction, Collaborative Design, Situated Learning and Mentoring/Coaching.

Knowledge instruction. By knowledge instruction in our project, we focus on **structured theoretical foundations** and **practical learning experiences**. This training approach prioritises building a solid theoretical base, which is needed for understanding pedagogical principles and instructional content. It provides the essential framework upon which other technology-enhanced learning methods can build. The knowledge instruction approach is rooted in constructivist learning theories, which emphasise the importance of integrating new information with existing knowledge to build more comprehensive mental models (Piaget, 1973, Vygotsky, 1978). Huang (2002) draws on the work of Dewey (1961) and Vygotsky (1962) which states that constructivism promotes and requires active and real-life learning, scaffolds on prior learning, necessitates reasoning processes, and demands social interaction. By engaging teachers in active learning processes such as discussions and problem-solving, this approach enhances their basic pedagogical knowledge, enriches their understanding of concepts, and fosters a reflective and adaptive mindset to develop skills, deepening content knowledge and fostering positive attitudes toward technology-integrated practices.

To operationalise this approach, we emphasise the following practices:

- **Instruction**: Instruction involves providing teachers with targeted advice and guidance on effectively implementing specific teaching methods. This includes delivering concrete, subject-specific information, facilitating knowledge acquisition, and promoting concept mastery. Such direct instruction lays a solid foundation for applying theoretical concepts in practical scenarios (Sims et al., 2023).
- **Hands-on learning**: Teachers gain knowledge through experiential learning, where they interact holistically with their environment, including the integration of new technologies. This approach allows teachers to create knowledge by engaging directly with tools and practices in a manner that mirrors real-world application (Wilson, 2023).
- **Work sample analysis**: Teachers analyse and review tasks and materials created by other practitioners, such as lesson plans, or analyse enacted lessons through mediums like videos. This reflective practice enables teachers to identify strengths and areas for improvement in technology-integrated lessons, fostering a deeper understanding of effective teaching strategies (Wilson, 2023).
- **Practice lesson planning**: Teachers individually plan simulated lessons that integrate technology, providing an opportunity to apply newly acquired knowledge in a controlled environment. This practice helps solidify their understanding and prepares them for actual classroom implementation.

Situated learning. By this training approach, we emphasise the **implementation of new methods in real-world settings and iterative reflection**. This method integrates knowledge with real-world practice by engaging teachers in an iterative process that goes beyond lesson planning. It focuses on designing, applying, and reflecting on teaching practices in authentic contexts, fostering the development of practical skills and adaptability. As new knowledge about student learning continues to reshape traditional disciplines, teachers face ongoing 'on-the-job' learning challenges. They must adapt to new content, principles, and representational practices while anticipating how best to support student learning in these evolving areas (Goldman et al., 2022).

Influenced by a situative perspective on learning (e.g., Brown et al., 1989), teacher professional learning researchers emphasise that teacher learning is a collective process that should be situated in authentic contexts of everyday teaching practices (Koellner & Jacobs, 2015). Teaching is inherently situated and requires teachers to adapt to real-time interactions with students (Borko, 2004). Teachers must apply their knowledge flexibly within the dynamic classroom context while maintaining core principles that support student learning. They need to grasp what to do, how to do it, and why it is important (Bereiter & Scardamalia, 2014; Darling-Hammond et al., 2007). Job-embedded professional development, integrated directly into real classroom practices, allows teachers to build understanding from genuine experiences where they can apply new knowledge. (Girvan et al., 2016; Lave & Wenger, 1991). Through supported systematic reflection, teachers are able to connect their prior knowledge and experiences with the integration of new knowledge into their mental models.

To effectively implement this approach, we focus on the following key practices:

- **Goal setting**: Teachers establish specific, actionable goals aimed at enhancing their technology integration practices. These goals should be tailored to address students' needs and guide decisions related to classroom implementation (Wilson, 2023).
- **Action planning**: Teachers develop detailed action plans outlining when and how they will implement changes in their teaching practices in future lessons. This planning helps to ensure that changes are systematic and deliberate (Sims et al., 2023).

- **Practice lesson planning**: Teachers design technology-integrated lesson plans adjusted to their specific teaching environments. This phase focuses on bridging the gap between theoretical knowledge and practical application, emphasising the contextualisation of teaching strategies to meet real-world classroom needs.
- **Rehearsal/field experience:** Teachers put their technology-integrated lesson plans into practice by teaching actual lessons. This hands-on experience allows them to test and refine their approaches in a real classroom setting (Wilson, 2023).
- **Reflection/self-evaluation**: Teachers engage in systematic reflection and self-evaluation of their technology integration practices. This process involves critically assessing their effectiveness and identifying areas for improvement (Wilson, 2023).
- **Practical social support:** Teachers receive practical advice and support from teacher training institutions to assist in the effective implementation of new practices. This support helps address challenges and enhance the application of technology in the classroom (Sims et al., 2023).

Collaborative design. By this training method, we highlight **the creation of shared artefacts**, peer interaction and collective expertise. The collaborative design process is central to this training method, promoting a shared understanding and development of instructional practices. Collaborative design in teacher professional learning is an approach that enhances professional learning by involving teachers in the creation of shared artefacts, such as lesson plans, teaching materials, or instructional strategies. Theoretically, this approach is grounded in a sociocultural perspective (see Vygotsky, 1978), which proposed that knowledge is constructed through social interactions and collaborative processes. Vygotsky emphasised the importance of social contexts and cultural tools in learning, suggesting that learners build understanding through dialogue and shared activities, for instance, co-created artefacts. Supported by the social environment of the collaborative group, this process facilitates deeper learning as teachers negotiate meaning and construct knowledge together. Another closely related approach, based on Knowledge Building Theory, focuses on advancing knowledge through collaborative work and continuous improvement (Bereiter & Scardamalia, 2014). It highlights the value of involving teachers in the iterative process of developing and refining teaching materials, which improves the quality of the resources and supports ongoing professional development.

While the primary focus of this approach is on the collaborative design of shared artefacts, it is important to acknowledge the significant impact of teachers' prior knowledge, attitudes, and skills on the collaborative process. Teachers' existing expertise and attitudes influence how effectively they engage in joint design activities, contribute to discussions, and collaborate on developing innovative solutions. Teachers' pedagogical beliefs shape their approach to collaborative design by influencing their engagement, collaboration dynamics, sense of ownership, and practical considerations (Gomez et al., 2022). Their foundational knowledge and skills shape their ability to participate meaningfully and therefore, understanding and addressing these individual factors is essential for maximising the benefits of collaborative design in professional learning. To effectively implement this approach, we focus on the following key practices:

- **Shared understanding** of design context and elements: A common understanding among teachers about the design goals, target group, and role of learning technologies to ensure that everyone is aligned on what needs to be designed.
- **Activating background knowledge**: A solid understanding of the subject matter or instructional content they are designing for. Providing relevant information and context to help teachers effectively integrate technology into their lesson plans.
- **Analysing case studies and examples**: Case studies or examples of successful technology-integrated lessons and instructional designs to understand effective practices and innovative strategies, while providing inspiration for their own collaborative design efforts.

- **Design sessions:** Teachers apply their understanding of the design context and criteria to create joint artefacts. Teachers collaboratively plan and develop technology-integrated lessons in groups.
- **Implementation planning:** Teachers devise strategies for applying the designed materials in the classroom and receive guidance on adapting the designs to different classroom environments.

Coaching and mentoring. By this training method in our project, we focus on **personalised expert guidance, advice, and support.** The one-on-one nature of mentoring provides targeted feedback and guidance for addressing individual development needs and building confidence in implementing new approaches. Collins and Kapur (2014) highlight that mentoring and coaching are crucial elements of cognitive apprenticeship by providing structured and personalised support for teachers. Coaching, grounded in social constructivist and situated learning approaches, involves regular, individualised assistance that helps teachers integrate theoretical knowledge with practical application. Through this personalised guidance, mentors enhance teachers' instructional practices, refine their skills, and foster a positive professional attitude. This approach promotes a growth mindset, encourages reflective practice (Schön, 1983), and increases confidence in implementing innovative strategies.

To operationalise this approach, we will focus on the following key practices:

- **Modelling**: Providing clear, observable examples of effective teaching practices, which serve as a visual guide for teachers to replicate and adapt (Sims et al., 2023).
- **Observations**: Facilitating opportunities for teacher trainers to observe teachers, and for teachers to observe both their peers integrating technology effectively in the classroom, provides valuable practical insights and mutual inspiration for improving teaching practices (Wilson, 2022).
- **Continuous feedback**: Delivering evaluative guidance based on observations of teaching practices, aimed at identifying areas for improvement and providing actionable advice (Sims et al., 2023).

Different teaching methods may be effective for teacher professional development, but they shape knowledge, skills, and attitudes at varying levels. **Each method contributes to developing integrated knowledge**, such as TPACK (Technological Pedagogical Content Knowledge), **though their focuses and impacts differ**. Knowledge instruction provides a foundational understanding of technology integration and pedagogy, laying the groundwork for basic skills and attitudes. Situated learning applies these concepts in real-world contexts, offering deeper, context-specific knowledge and practical skills through hands-on experience. Collaborative design focuses on shared creation and group reflection, enhancing pedagogical understanding, and fostering collaborative skills. Mentoring, with its personalised guidance, deepens both theoretical knowledge and practical skills while having a more direct influence on attitudes and beliefs about teaching. In our literature review, **we will use this classification of training methods to analyse how different approaches have an effect on teachers' pedagogical digital competence**. By examining how each method shapes knowledge, skills, and attitudes, particularly in the context of integrated knowledge like TPACK, we can assess the effectiveness of teachers' PDC training.

3 Research questions

Building on the theoretical framework in Section 2, which defines the core components of effective teacher training as established in D2.1 (Seufert et al, 2024), we now turn to the specific research questions that guide our literature review. These questions focus on identifying the elements within teacher training interventions that effectively enhance teachers' PDC and subsequently impact student learning outcomes. The research questions form the foundation of our analysis, directing our methodological choices and shaping the review of existing studies. Through this targeted inquiry, we seek to understand what elements make pre-service and in-service teacher PDC training interventions effective. More specifically, we focus on the following research questions:

1. *What kind of interventions are employed in* ***pre-service and in-service teacher PDC***

training?

a) Type of training (e.g., workshop, seminar, etc.)

b) Content of the training (e.g., technology integration in mathematics education)

c) Target group (e.g., pre-service or in-service teachers)

d) Duration (e.g., one semester)

e) Delivery mode (e.g., online, face-to-face, blended learning)

2. *Which **training methods and practices** are employed in effective teacher PDC training interventions?*
3. *What are the effects of these interventions on **teachers' knowledge and affective-motivational dispositions** within their PDC?*
4. *What are the effects of these interventions on **teachers' classroom practices and behaviour** within their PDC?*
5. *What are the effects of these interventions on **student outcomes**?*

a) Regarding their **subject-specific skills**

b) Regarding their d**igital competence**

c) Regarding their self-regulated learning skills

4 Method

Over the past few decades, a considerable amount of studies has been published on the effects of pre-service and in-service teachers`PDC training. This body of research has already been synthesised in several systematic literature reviews and meta-analyses. To answer our research questions, an umbrella review was therefore deemed the most suitable approach. Given the breadth and depth of existing syntheses, an umbrella review enables us to consolidate insights from various reviews into a single, comprehensive overview, identifying overarching trends, gaps, and convergences within the body of knowledge. Following the guidelines for conducting systematic umbrella reviews by Aromataris et al. (2015), this approach allows us to synthesise findings across a range of studies with diverse methodologies, participant populations, and contextual settings, thus providing a higher-level perspective on effective elements of PDC training interventions.

4.1 Inclusion and Exclusion Criteria

Before the literature search, inclusion and exclusion criteria for selecting literature were defined (see Table 1).

Table 1. Inclusion and exclusion criteria for literature selection

Criterion	Inclusion	Exclusion
Target group of the training	Pre-service teachers In-service teachers	Teacher educators Higher education teachers
Content of the training	Pedagogical Digital Competence (PDC)	Other contents
School context (in which teachers work)	Primary education Secondary education	Early childhood education Tertiary education
Disciplinary field	All fields	-
Time period	2000 – 2024	Studies outside this period
Type of article	Systematic literature review or meta-analysis published in a peer-reviewed journal or conference proceedings	Primary empirical studies
Language	English	Non-English articles
Country	Studies from all countries	-
Dependent variables – teacher level	Pedagogical digital competence (at least one of the dimensions described in the theoretical framework has to be assessed)	Studies that did not include one of the dimensions
Dependent variables – student level	Student learning outcomes • Subject-specific skills / student achievement • Digital competence • Self-regulated learning skills	Since studies with student-level data are quite rare in this context, the non-existence of student-level data was not an exclusion criterion.

4.2 Literature Search and Article Selection

As a first step, three databases were examined for relevant literature: (1) Scopus, (2) Web of Science, and (3) Science Direct. The following search phrase with Boolean operators was used: ("teacher professional development" OR "teacher training" OR "teacher education" OR "teacher learning") AND ("pedagogical digital competence" OR "TPACK" OR "technology integration") AND ("systematic review" OR "meta-analysis").

In addition, six highly relevant journals in the field, including *Computers & Education*, *Computers in Human Behavior*, *Teaching and Teacher Education*, *Educational Research Review*, *European Journal of Teacher Education,* and *Professional Development in Education,* were searched. The web search engine Google Scholar was also used to locate articles that may not have been published in peer-reviewed journals. The articles obtained and related umbrella reviews (e.g., Wohlfart & Wagner, 2023; Peters et al., 2022) were cross-referenced.

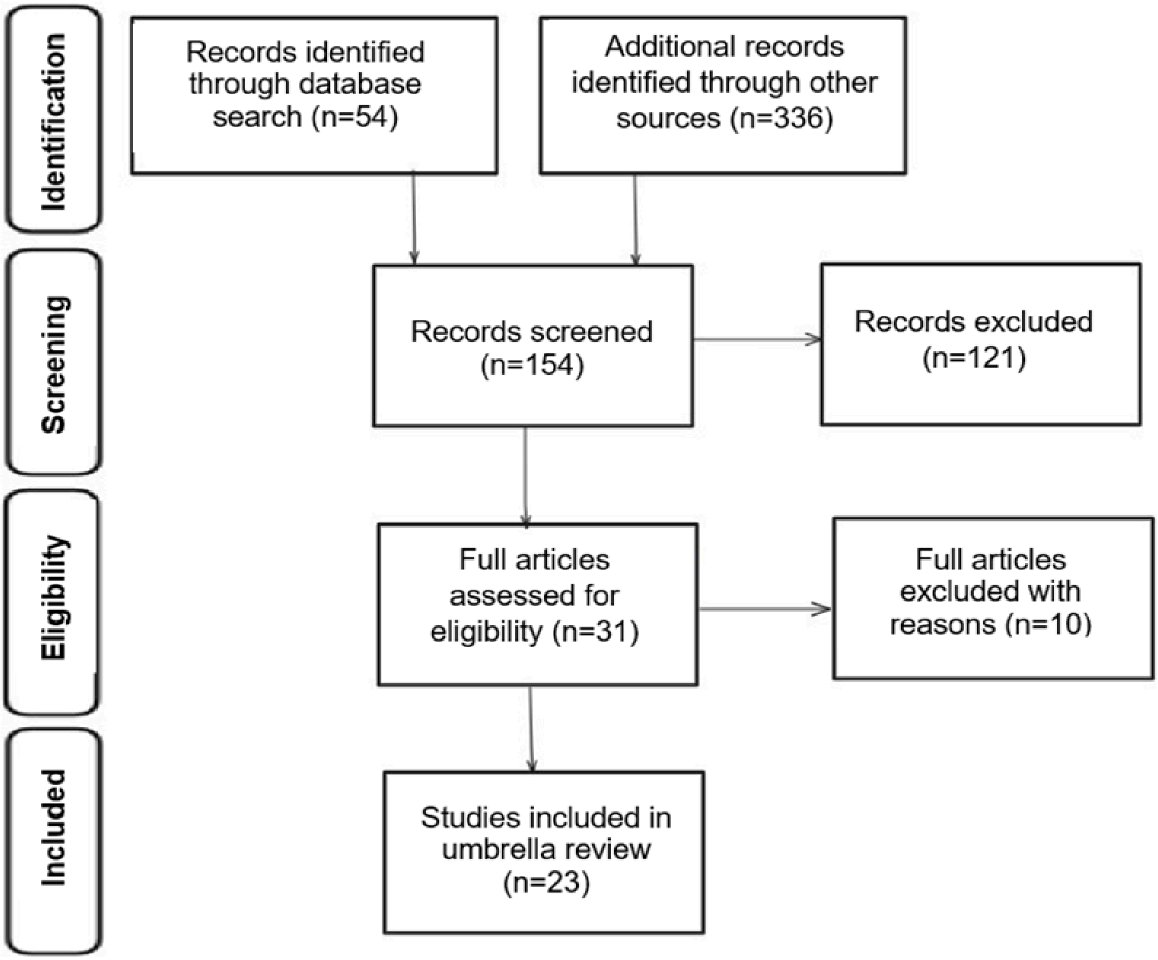

Figure 2. Article selection process

During the systematic literature search, the preferred reporting of items for systematic reviews and meta-analyses (PRISMA) statement provided by Moher et al. (2009) was followed. Using the search phrase mentioned above in **April 2024**, we identified *n*=24 papers in Scopus, *n*=22 papers in the Web of Science, and *n*=8 papers in ScienceDirect. In Google Scholar, we modified the search phrase[1] to further narrow down the results and got 336 results, of which we checked the first 100 results. After examining the titles and abstracts of the articles identified in the databases and Google Scholar, several articles were considered irrelevant to the umbrella review because they did not focus on teacher

[1] ("teacher professional development" OR "teacher training" OR "teacher education" OR "teacher learning") AND ("pedagogical digital competence" OR "TPACK" OR "technology integration") AND ("systematic review" OR "meta-analysis") AND "effective design"

training interventions, were written in languages other than English, were themselves an umbrella review, or focused on different target groups (e.g., teacher educators or early childhood teachers). Finally, 31 full-text articles were assessed for eligibility. Of these, 10 were excluded for various reasons (e.g., no empirical data provided but rather descriptive, focus not on teacher training intervention). All in all, **23 articles were included in the final analysis**.

4.3 Coding and data analysis

A total of nine reviewers were involved in the coding process. To establish a common understanding of the coding procedure, all reviewers first reviewed two papers together and clarified any uncertainties before moving on to the remaining papers, which were evenly distributed among them. The process was facilitated by the use of a shared Excel spreadsheet (available here).

Based on the guidelines of Aromataris et al. (2015), the following aspects of each publication were coded: citation details (title, year, journal), objectives of the included review, type of review (e.g., systematic literature review or meta-analysis), participant details, setting, context, date range of database search, number of and types of studies, reported outcomes relevant to our research questions, methods of evidence synthesis, and implications for future research. The data resulting from the reviews was then checked for inconsistencies, with at least two authors independently reviewing each paper. Any inconsistencies were then discussed by the whole group.

To answer our research questions, we conducted both quantitative and qualitative content analyses of the selected 23 systematic reviews and meta-analyses. For the quantitative analysis, descriptive statistics were employed to calculate the percentage frequencies of study characteristics. Qualitative content analysis was used to summarise the results related to our five research questions. The identified results were discussed by the whole team of reviewers.

4.4 Overview of the Included Studies

This umbrella review analysed **23 studies** published between 2006 and 2024, with the majority (70%) conducted in or after 2020. The systematic reviews encompass studies ranging from 1997 to 2023, reflecting evolving trends in the field. The **number of studies** reviewed in each paper varied significantly from as few as 11 to as many as 170, with a wide range of research designs represented, including quantitative, qualitative, and mixed methods.

Sample sizes across the included systematic reviews also varied widely, with the smallest sample comprising just 4 participants while the largest reached 2,828. This diversity in sample size reflects the varied scope and focus of the studies included in this review.

Geographically, the studies demonstrate a **wide international scope** covering countries such as Australia, Germany, the United Kingdom, the USA, France, Canada, China, Norway, Pakistan, Indonesia, South Africa, Puerto Rico, and Kenya. Notably, the USA dominated as the most frequently represented country.

Regarding **subject focus**, several studies explored the development of teachers' Technological Pedagogical Content Knowledge (TPACK) across disciplines such as mathematics, science, language and literacy, English, humanities, and special education. While other studies had a broader focus, investigating the integration of technology into education more generally.

This global and thematic diversity highlights the range of research conducted in the field and underscores the importance of technology integration in education across multiple contexts and disciplines.

5 Results

5.1 Teacher PDC training interventions

This section provides an overview of the interventions employed in pre- and in-service teacher PDC training. The studies included in this umbrella review are examined in terms of the type and content of the intervention, target group, duration of the training, and delivery mode as presented in Table 2.

Table 2. Summary of the PDC Training

No.	Author	Type and Content of the Training	Target Group	Duration	Delivery Mode
1	Atmacasoy and Aksu (2018)	Teacher education courses from different departments (e.g., Biology Education, Computer Education and Instructional Technologies)	Pre-service teachers	4 weeks - one term	Blended
2	Bragg et al. (2021)	Professional development programmes on content knowledge (CK) and pedagogical content knowledge (PCK)	In-service teachers	Varies from several weeks to a full academic year	Online (asynchronous and synchronous)
3	Chai (2019)	Professional development programmes for STEM education based on TPACK	Pre- and in-service teachers	Varies from hours to year	N/A
4	Fahrurozi et al. (2019)	Teacher education courses to improve teachers' TPACK	Pre-service teachers	In some studies five consecutive semesters	N/A
5	González et al. (2024)	Training courses on the integration of technology based on TPACK	In-service teachers	Varies from 2 sessions of 90 minutes each to 16 weeks	Face-to-face, online and blended

No.	Author	Type and Content of the Training	Target Group	Duration	Delivery Mode
6	Hennessy et al. (2022)	Professional development courses to improve teachers' content, pedagogical and technological knowledge	Pre- and in-service teachers	Varies from short-term to long-term	Online and blended
7	Huang et al. (2022)	STEM teacher professional development programmes based on TPACK	Pre- and in-service teachers, library STEM facilitators	Varies from 1 week to a two-month program	N/A
8	Jiménez Sierra et al. (2023)	Lesson study interventions to develop TPACK	Pre- and in-service teachers	N/A	Online, face-to-face
9	Kay (2006)	Teacher education courses that incorporate technology	Pre-service teachers	N/A	Online, face-to-face
10	Ning et al. (2022)	Teacher education interventions to improve teachers' TPACK	Pre- and in-service teachers	Varies from 0~3 months to more than 6 months	Online, offline and hybrid
11	Perry et al. (2021)	Teacher education and professional development courses on different subjects	Pre- and in-service teachers	Varies (short-term to long-term training sessions)	Online or blended
12	Rodríguez et al. (2024)	Training courses focusing on STEM education	Pre- and in-service teachers	Varies from 2 days to 13 weeks	Online and face-to-face
13	Røkenes et al. (2014)	ICT training in teacher education	pre-service teachers, mixed in-service and student teachers	N/A	Online and face-to-face
14	Schmid et al. (2023)	Teacher education and professional development courses on different subjects	Pre- and in-service teachers	N/A	Online, blended, face-to-face

No.	Author	Type and Content of the Training	Target Group	Duration	Delivery Mode
15	Smith and Becker (2021)	Communities of Practice (CoP) to facilitate teacher professional learning regarding classroom technology integration	In-service teachers	Varies from less than a year to 2 years	N/A
16	Surahman & Wang (2023)	STEM professional development programmes based on TPACK (e.g. workshops)	In-service teachers	Varies from 0–6 months to more than 48 months	N/A
17	Teo et al. (2021)	Teacher education courses focusing on 21st-century skills and technology integration	Pre-service teachers	N/A	N/A
18	Tondeur et al. (2012)	Teacher education courses on technology integration in the classroom	Pre-service teachers	N/A	N/A
19	Wang et al. (2018)	Teacher education courses to develop TPACK	Pre-service teachers	Varies from 2 years to 11 months	N/A
20	Wilson et al. (2020)	Teacher education courses for technology integration	Pre-service teachers	Courses as part of a four- or five-year program	N/A
21	Wilson (2023)	Teacher education courses for technology integration	Pre-service teachers	Courses as part of a four- or five-year program	N/A
22	Wu (2023)	Telecollaboration ("virtual exchange") interventions in language teacher education	N/A	Varies from short-term to long-term	online
23	Yeh et al. (2021)	"Learning by design" interventions to develop TPACK	Pre- and in-service teachers, university teachers	Varies from 5 weeks to 2 semesters	Face-to-face and online

Given that the current study is an umbrella review, the training content of the individual studies included within each systematic review may be difficult to define. Therefore, broad terms were used to capture the overall content of the training delivered, aligned with each study's objectives. The included studies mostly focused on the integration of technology in education as part of teacher education courses for pre-service teachers and/or professional development programs for in-service teachers. Some studies explicitly adjusted the TPACK framework to enhance teachers' PDC across various subjects (n=9). Of the included studies, 43% (n=10) targeted both pre- and in-service teachers, with three also involving other groups, such as university teachers, teacher trainers, and library STEM (Science, Technology, Engineering, and Math) facilitators. In eight studies (35%), interventions were delivered solely to pre-service teachers, while in four studies, only in-service teachers participated. Interestingly, Ning et al. (2021) found in their meta-analysis that teacher education interventions had a more profound impact on pre-service teachers' TPACK than on in-service teachers', possibly because pre-service teachers are still in the early stages of their professional development.

With regard to the **duration** of the interventions, it is observed that there is a considerable difference between interventions. In most studies explicitly reporting the length of interventions, 52% (*n*=12) varied in duration from short- to long-term. However, there are also a few studies (*n*=3) in which only long-term interventions, such as courses as part of a four- or five-year programme (Wilson et al., 2020; Wilson, 2023) and courses lasting 11 months to 2 years, were examined (Wang et al., 2018). Ning et al. (2022) found in their meta-analysis that the effectiveness of teaching interventions in improving teachers' TPACK increases with the length of the intervention.

The training was delivered to the participants in **different forms**, such as online, face-to-face, blended, and hybrid. 43% of the studies (*n*=10) did not specify the mode of delivery. Although the effectiveness of the training in different modes has not been investigated in the majority of the included studies, the study of Ning et al. (2022) showed that blended learning interventions demonstrated the greatest effect size compared to online and offline teaching. Furthermore, it was found by Atmacasoy and Aksu (2018) that a blended learning environment fostered positive attitudes among pre-service teachers toward their courses. However, there is a lack of sufficient studies to provide robust evidence regarding not only the delivery mode but also the duration of the intervention, which makes it difficult to draw firm conclusions about effective teacher training to enable teachers to integrate technology into their teaching contexts.

5.2 Training methods and key practices employed in teacher PDC training interventions

In this section, various training methods and key practices for teacher PDC training interventions are examined. **It was observed that only a few studies explicitly focused on the teacher training methods as part of their research objectives** (e.g., Røkenes, 2014; Ning et al., 2022; Wilson et al., 2020; Wilson, 2023). In contrast, other studies described training methods more generally, emphasising teaching strategies or activities such as peer collaboration, scaffolding, workshops, and feedback (e.g., Kay, 2006; Teo et al., 2021; Tondeur et al., 2012). Five studies did not specify any design elements related to the training methods (Atmacasoy and Aksu, 2018; Fahrurozi et al., 2019; Perry et al., 2021; Schmid et al., 2023; Wu, 2023). Table 3 presents a classification of 18 studies in which design elements were described to varying degrees—whether implicitly, partially, or explicitly. These studies were categorised based on key practices aligned with four core training methods of our EffecTive framework: knowledge instruction, situated learning, collaborative design, and mentoring/coaching, each of which is discussed in detail in Section 2.3.

Table 3. Frequency of Key Practices in Teacher PDC Training

Key Practice	N	Author(s)
Reflection/ self-evaluation	14	Bragg et al. (2021), Chai (2019), Hennesy et al. (2022), Huang et al. (2022), Jiménez Sierra et al. (2023), Rodríguez et al. (2024), Røkenes et al. (2014), Smith et al. (2021), Surahman and Wang (2023), Tondeur (2012), Wang et al. (2018), Wilson et al. (2020), Wilson (2023), Yeh et al. (2021)

Key Practice	N	Author(s)
Hands-on learning	9	Bragg et al. (2021), Chai (2019), Gonzales et al. (2024), Huang et al. (2022), Rodríguez et al. (2024), Røkenes et al. (2014), Tondeur et al. (2012), Wilson et al. (2020), Wilson (2023)
Practice lesson planning/design sessions	9	Chai (2019), Gonzales et al. (2024), Huang et al. (2022), Jiménez Sierra et al. (2023), Ning et al. (2022), Surahman and Wang (2023), Wilson et al. (2020), Wilson (2023), Yeh et al. (2021)
Instruction	8	Bragg et al. (2021), Chai (2019), Gonzales et al. (2024), Hennesy et al. (2022), Huang et al. (2022), Rodríguez et al. (2024), Tondeur (2012), Yeh et al. (2021)
Rehearsal/field experience	8	Bragg et al. (2021), Chai (2019), Huang et al. (2022), Jiménez Sierra et al. (2023), Kay (2006), Wang et al. (2018), Wilson et al. (2020), Wilson (2023)
Work sample analysis/analysing case studies	6	Gonzales et al. (2024), Huang et al. (2022), Surahman and Wang (2023), Wilson et al. (2020), Wilson (2023), Yeh et al. (2021)
Goal setting	6	Jiménez Sierra et al. (2023), Kay (2006), Smith et al. (2021), Wilson et al. (2020), Wilson (2023), Yeh et al. (2021)
Modelling	6	Hennesy et al. (2022), Kay (2006), Røkenes et al. (2014), Teo et al. (2021), Tondeur et al. (2012), Wang et al., (2018)
Mentoring	5	Chai (2019), Kay (2006), Teo et al., (2021), Wilson et al. (2020), Wilson (2023)
Observation	4	Rodríguez et al. (2024), Wang et al., (2018), Wilson et al. (2020), Wilson (2023)
Scaffolding	4	Huang et al. (2022), Ning et al. (2022), Teo et al., (2021); Tondeur et al. (2012),
Implementation planning	3	Gonzales et al. (2024), Jiménez Sierra et al. (2023), Surahman and Wang (2023)
Feedback	3	Huang et al. (2022), Tondeur et al. (2012), Hennesy et al. (2022)
Problem-based learning	3	Ning et al. (2022), Rodríguez et al. (2024), Røkenes et al. (2014)
Project-based learning	2	Huang et al. (2022), Rodríguez et al. (2024)

Key Practice	N	Author(s)
Game-based learning	1	Ning et al. (2022)

It should be noted that none of the included studies explicitly mentioned the use of a certain training method as described in Section 2.3, such as knowledge instruction, collaborative design, etc. However, when describing their training approaches, we found that key practices typically associated with these methods were often employed. Two studies focused on training strategies that utilised a single approach, such as lesson study (Jiménez Sierra et al., 2023) and communities of practice (Smith et al., 2021). In several other studies, **different key practices from various training methods were combined** within interventions to achieve desired outcomes. For example, in Yeh's (2021) study, the learning-by-design approach, where teachers collaborate and learn from each other, was employed to enhance teachers' TPACK. This training approach incorporated four key strategies to foster teacher collaboration, aligning with practices from both collaborative design and situated learning. As a result, the study drew upon a blend of these two approaches in its key practices.

As shown in Table 3, **reflection/self-evaluation stood out as the most frequently reported key practice**, appearing in almost 61% of the included studies (*n*=14). Notably, reflection was not only used as a component of situated learning but was often combined with other training methods. Hennesy et al. (2022) highlighted that video-based, self-reflective teacher professional development was particularly common and highly effective, as it allows teachers to observe themselves in action and evaluate their practices. This process of reflection helps teachers rethink their instructional strategies and adapt them when integrating technology into their teaching (Smith et al., 2021).

Hands-on learning and practice lesson planning/design sessions were identified as the second most frequently mentioned key practice, cited in 39% of the studies (*n*=9). Hands-on learning allows teachers to actively engage in integrating technology into their teaching by participating in meaningful, experiential learning processes (Røkenes et al., 2014). Practice lesson planning/design sessions, which refer to developing lesson plans individually or collaboratively by incorporating elements of knowledge instruction and collaborative design, were cited as often as hands-on learning. In most cases, this practice was applied in group settings during teacher training, allowing teachers to learn from one another while planning lessons. Teacher PDC training interventions are more likely to facilitate effective changes in both subject knowledge and pedagogy when teachers are given opportunities to create digital teaching and learning materials (Hennesy et al., 2022). It is interesting that **although teachers reported gaining new knowledge and skills, some were still reluctant to implement the lesson plans they had developed in their own classrooms.** (Chai, 2019).

The third most frequently mentioned key practices were instruction and rehearsal/field experience, cited in 35% of the studies (*n*=8). Instruction often served as the initial step to equip teachers with foundational knowledge before moving on to other key practices (e.g., Yeh et al., 2021). In some instances, instruction was integrated with practical experience, referred to as aligning theory with practice (Tondeur et al., 2012; Huang et al., 2022). Ning et al. (2021) noted that **while teachers are generally open to theoretical knowledge, many struggle to apply it in real classroom settings.** To address this gap, it is crucial to connect theoretical concepts with practical application rather than presenting them as isolated content. This approach not only helps teachers better understand the rationale behind technology integration in teaching (Tondeur et al., 2012) but also provides them with the opportunity to gain field experience in real school contexts.

Through the incorporation of rehearsal and field experience in teacher training, participants' attitudes towards technology shifted from focusing on personal skills to developing teaching skills as they gained practical experience (Røkenes et al., 2014). Providing teachers with authentic opportunities to experiment with technology-based teaching methods was also seen as crucial (Wang et al., 2018). Notably, **training**

interventions embedded in practical application demonstrated significant improvements in participants' instructional practices (Bragg et al., 2021).

Work sample analysis/analysing case studies and examples refers to analysing and reviewing designs and examples of lesson plans individually or collaboratively created by other practitioners. This key practice was applied in six studies. For example, it was implemented in the study of Gonzales et al. (2024) to teach maths by analysing the available digital sources and discussing the integration of these in the classroom.

Goal setting emerged as another recurring theme, identified in 26% of the reviewed studies (*n*=6). For example, in the study of Jiménez Sierra et al. (2023) in which lesson study was adopted as a strategy, goal setting was used to determine the learning objective in the first stage before lesson enactment.

Modelling (*n*=6), **mentoring** (*n*=5) and **observation** (*n*=4) which are principally based on a relationship between novice and experienced teachers with differences in application were also reported in the included studies**.** **Modelling** enables teachers to acquire practical skills for technology integration (Røkenes et al., 2014; Teo et al., 2021). A major limitation, however, is that teachers may miss the opportunity to design and implement their own technology-based lessons (Kay, 2006). We also noticed that in some studies (Chai, 2019, Kay, 2006, Teo et al., 2021, Wilson et al., 2020, Wilson, 2023) **mentoring** was mentioned broadly as a support of the technology-integrating teacher (Wilson et al., 2020). Therefore, we decided to include a theme called "mentoring", which refers broadly to the collaboration between the teacher/trainer and novice teacher for the studies in which mentoring was mentioned with no or little information about its application**. Although mentoring shows significant potential for enhancing the effective use of technology in the classroom, there is still limited empirical evidence supporting its impact** (Kay, 2006).

Observation and feedback were found to be less frequently employed in teacher training. In the studies in which observation was used as a key practice, the importance of teachers as role models was highlighted. Based on the collected evidence, Tondeur et al. (2012) concluded that **observing a teacher effectively using technology serves as a significant motivator.** On the other hand, feedback, which refers not only to evaluative guidance on tasks and content but also to teaching practices followed by observation, was reported much less frequently (*n*=3).

While the majority of practices fall under the categories of the four training methods, **other approaches were also identified, albeit less frequently.** For instance, scaffolding, in which the instructor supports learners in developing a specific skill or knowledge (Wood et al., 1976), was utilised as a training approach to support teachers to gain independence to integrate technology in their teaching contexts (*n*=4).

Problem-based learning was mentioned in three studies (Ning et al., 2022; Rodríguez et al., 2024; Røkenes et al., 2014), highlighting an emphasis on problem-solving and critical thinking. Rodríguez et al. (2024) concluded that problem-based learning programmes assessed teachers' problem-solving abilities by applying scientific knowledge in both simulated scenarios and real curriculum-related situations, as well as through problem-solving tasks focused on developing computational thinking. **Project-based learning** was examined in two studies (Huang et al., 2022; Rodríguez et al., 2024), both highlighting hands-on, inquiry-based teaching. The training programmes that employed a project-based learning approach utilised a model rooted in practical research exercises, aiming for the integration of context within the learning process (Rodríguez et al., 2024). Similarly, **game-based learning** appeared only in the study of Ning et al. (2021), focusing on interactive and gamified approaches to teacher training. Although these methods were less frequently mentioned and are not associated with the primary training categories, they represent important approaches that contribute to a more varied teacher training landscape.

In conclusion, reflection and self-evaluation emerged as the **most frequently applied key practice** in teacher training (61%), followed by hands-on learning (39%), practice lesson planning/design sessions (39%), and instruction and rehearsal/field experience (35%). In contrast, feedback, problem-based, project-based, and game-based learning were among **the least reported practices**. Despite the emphasis on these key practices, the majority of the reviewed studies focused more on describing the training elements rather than comparing key practices and evaluating their effectiveness. **Only a few studies provided results on the outcomes of different key practices, and none yielded consistently positive results** (Wilson et al., 2020; Wilson, 2023). These findings indicate that although various key practices are applied in teacher PDC training interventions, evidence on their comparative effectiveness in enhancing teacher outcomes remains limited.

5.3 Effects on teachers' knowledge and affective-motivational dispositions within their PDC

This part of the deliverable presents an overview of the results regarding the effects of teacher training interventions on teachers' knowledge and affective-motivational dispositions as part of their PDC. By synthesising the reported results, we aim to build an understanding of what dimensions of teachers' PDC have been investigated in empirical research so far and how they have been influenced by teacher training interventions. Therefore, in this section we first present a general overview on the level of teacher education/training addressed by the studies and then focus specifically on (1) effects on teachers' TPACK; (2) effects on teachers' motivation and changes in attitude.

Of the 23 studies, **20 (87%) referred to the effects on teachers' knowledge and/or affective-motivational dispositions.** 8 studies (35%) focused on pre-service teachers (Atmacasoy & Aksu, 2018; Kay, 2006; Røkenes et al., 2014; Teo et al., 2021; Tondeur et al., 2012; Wang et al., 2018; Wilson et al., 2020; Wilson, 2023); 3 (13%) studies focused on in-service teachers (Bragg et al., 2021; González et al., 2024; Smith et al., 2021); and 8 (40%) examined a combined population of in- and pre-service teachers together (Fahrurozi et al. 2019; Hennessy et al. 2022; Huang et al. 2022; Jiménez Sierra et al. 2023;

Ning et al. 2022; Perry et al. 2021; Schmid et al. 2023; Yeh et al. 2021). In one case (4%; Wu, 2023), this information was not explicitly mentioned.

5.3.1. Effects on teachers' TPACK

Of the 23 studies, **11 (48%) focused on the effects on teachers' TPACK** (Bragg et al., 2021; Fahrurozi et al., 2019; González et al., 2024; Hennessy et al., 2022; Huang et al., 2022; Jiménez Sierra et al., 2023; Ning et al., 2022; Perry et al., 2021; Wang et al., 2018; Yeh et al., 2021; Wilson et al., 2020). Teacher PDC training interventions in both pre-service teacher education and in-service teacher professional development generally lead to positive improvements in teachers' TPACK across multiple constructs. Courses based on the TPACK framework often enhance teachers' CK, PK, TK, and combinations of these constructs (see Bragg et al., 2021; Fahruozi et al., 2019; Gonzalez et al., 2024; Jimenez Sierra et al., 2023; Ning et al., 2022; Perry et al., 2021; Wang et al., 2018). Hennesy and colleagues (2022) also reported that interventions changed not only teachers' PK but also improved their subject CK. Nevertheless, some studies show that while pre-service teachers recognised the value of TK and PK, they often struggled to fully apply it to develop their TPACK, with first-year pre-service teachers often showing limited development in TK, PK, and TPK (Wang et al., 2018). Moreover, TK is often the weakest area in teachers' TPACK development (Gonzalez et al., 2024).

Some differences have been identified with regards to **specific subject domains** of teachers' professional development interventions. For example, Huang et al. (2022) conclude that such interventions in STEM disciplines mainly focus on TCK and TPCK due to the nature of the taught subjects (e.g., engineering), which are not characteristics of traditional teacher training interventions. Additionally, longer-lasting interventions that integrate information technology have a greater impact on teachers' TPACK development than short-term interventions (Ning et al., 2022). Collaborative approaches also show promise in fostering TPACK (see, e.g., Jiménez Sierra et al., 2023; Røkenes et al.

(2014); Smith et al., 2021; Yeh et al., 2021), for example, by promoting equal participation (Yeh et al., 2021). Collaborative discussions among pre-service teachers, in-service teachers, and university professors allowed them to share their individual TPACK, expanding it into a collectively developed TPACK enriched by their shared experiences and insights.(Yeh et al., 2021).

5.3.2. Effects on teachers' affective-motivational dispositions

Teachers' motivation to use digital technology in the classroom, along with their attitudes toward it, are key factors that impact both their integration of technology into practice and the transfer of knowledge. In our analysis, 7 (30%) out of 23 studies focused on teachers' motivation and changes in attitude (Atmacasoy et al., 2018; Bragg et al., 2021; Hennessy et al., 2022; Hunag et al., 2022; Schmid et al., 2023; Smith et al., 2021; Wilson, 2023). Overall, the studies show a positive impact on their motivation in terms of different constructs, e.g., self-efficacy, confidence, and beliefs, particularly towards technology use in education (see Atmacasoy et al., 2018; Bragg et al., 2021; Hennessy et al., 2022; Schmid et al., 2023). For example, one meta-analysis found that technology integration courses greatly improved pre-service teachers' attitudes and beliefs about using technology in education (Wilson, 2023). Teachers' confidence and pedagogical beliefs can also be boosted when they are provided with the opportunities to acquire pedagogical content knowledge (Huang et al., 2022). Similarly, Smith et al. (2021) found out that most of the studies they reviewed reported positive changes in teacher beliefs, including improved attitudes towards technology, increased empowerment, greater confidence, and shifts in teaching perspectives. Nevertheless, some studies showed that a mix of positive and negative attitudes affected teachers' practices and innovation in the classroom (Smith et al., 2021). Moreover, blended learning approaches often outperformed online-only formats in terms of teacher satisfaction, self-efficacy, and better achievement (Atmacasoy & Aksu, 2018; Schmid et al., 2023).

In summary, the findings emphasize that teachers' motivation, attitudes, and confidence toward using digital technology are critical to its successful integration into classroom context. This underscores the need for interventions that not only build technological skills but also foster positive beliefs and motivation, ultimately empowering teachers to use technology more effectively and confidently in education.

5.4 Effects on teachers' classroom practices and behaviour

This chapter aims to synthesise the findings of the included studies regarding the impact of teacher PDC training interventions on teachers' classroom practices and their behaviours. By examining the reported effects, we seek to provide insights into how these programmes influence teachers' pedagogical approaches and technology integration.

Of the 23 studies analysed, **16 (70%) referred to the impact on teaching practices, including technology integration practices.** Specifically, **9 studies (56%) focused on the examination of the impact on teaching practices only indirectly**, i.e., by assessing teachers' knowledge, perceptions, and attitudes toward technology integration rather than evaluating actual classroom implementation (Atmacasoy and Aksu, 2018; Ning et al., 2022; Rodríguez et al., 2024; Schmid et al., 2023; Teo et al., 2021; Tondeur et al., 2012; Wang et al., 2018; Wu, 2023, Yeh et al., 2021). In contrast, **7 studies (44%) focused on the examination of both the direct impact on classroom practices and the indirect impact** through perceptions and knowledge (Bragg et al., 2021; González et al., 2024; Hennessy et al., 2022; Huang et al., 2022; Perry et al., 2021; Røkenes et al., 2014; Smith et al., 2021). The analysis of these articles highlights how teacher training contributes to improving pedagogical practices and how different design elements of the training influence this improvement.

A key finding from this review is the improvement in **teachers' ability to integrate technology into their teaching processes.** Many training programmes resulted in teachers adopting technological tools and gaining a deeper understanding of how to use technology in lessons, making teaching more dynamic and better tailored to student needs (Atmacasoy & Aksu, 2018; González et al., 2024; Hennessy et al., 2022; Perry et al., 2021; Røkenes et al., 2014; Smith et al., 2021; Wu, 2023). Another impact was seen in enhancing **student-centred teaching**. The training helped teachers develop the ability to create more opportunities for active student engagement, designing classrooms focused on active and collaborative learning (Huang et al., 2022; Smith et al., 2021; Wang et al., 2018).

Additionally, the training programmes improved **teachers' lesson planning and design skills**. Teachers improved their competences, enabling them to plan lessons more thoughtfully based on technological-pedagogical-content knowledge (TPACK), contributing to more effective technology integration in lessons (González et al., 2024; Ning et al., 2022; Teo et al., 2021; Tondeur et al., 2012). However, some studies noted that despite improvements in technological knowledge, there wasn't always a direct translation to classroom implementation (Yeh et al., 2021).

5.5 Effects on Student Outcomes

This chapter synthesises the findings of the included studies regarding the impact of teacher PDC training interventions on student outcomes. Our analysis has shown that **research into teacher training interventions and the use of technology provides limited impacts on student outcomes**. Atmacasoy and Aksu (2018) have reported positive effects, such as decreasing dropout rates, fostering high student engagement, and enhancing exam scores. These benefits are closely linked to improvements in student performance (Atmacasoy & Aksu, 2018). For instance, thoughtful integration of technology in the classroom has been shown to significantly improve learning outcomes, suggesting that when used effectively, technology can have a substantial positive impact on **student achievement** (Kay, 2006).

Furthermore, teachers have reported that the use of digital technologies has increased **students' motivation** (González et al., 2024). This aligns with broader research indicating that enhancing students' learning experiences through such technologies can maximise engagement and learning (Hennessy et al., 2022).

However, the **impact of these interventions on student achievements has shown to be inconsistent**. While some studies have reported improvements in specific areas, such as reading comprehension and maths, others have found no significant changes or only minimal, statistically non-significant, improvements in subjects like maths and biology (Bragg et al., 2021). This mixed evidence underscores the importance of context and implementation in determining the effectiveness of educational strategies. Further evidence supports the positive effects of various interventions on academic achievement, including standardised test scores and vocabulary skills. Studies have shown that these strategies can lead to enhanced behaviour, knowledge, and learning outcomes (Perry et al., 2021). Additionally, other research has highlighted improvements in students' subject matter knowledge and computer skills (Røkenes et al., 2014).

Non-cognitive dimensions, such as student engagement and enjoyment, are also critical in evaluating the success of educational interventions. Seven articles have explored these aspects, demonstrating their significance despite variations in measurement methods and reporting (Smith et al., 2021). For example, Zorfass and Rivero (2005) provided anecdotal evidence of improved student performance in their study, though the specifics were less detailed. In summary, while evidence suggests that enhancing student learning outcomes and engagement is achievable through effective teaching practices and technology integration, the results can vary. Active learning processes and thoughtful use of digital tools play a crucial role in promoting better student engagement and performance (Wang et al., 2018; Hennessy et al., 2022). Understanding these nuances helps in tailoring interventions to maximise their impact on student success.

6 Discussion

6.1 Discussion of the main findings

The purpose of Deliverable 1.2 is to provide a comprehensive overview of the elements that contribute to effective teacher training interventions and their potential impact on teachers' PDC and student learning outcomes. Through our umbrella review, we systematically examine the **characteristics of interventions** designed to improve PDC in both pre-service and in-service teachers (RQ1). Additionally, we analyse the **key practices** that underpin successful teacher education courses for pre-service teachers and professional development programs for in-service teachers (RQ2). We also investigate the **effects of these interventions** on teachers' **PDC** (RQ3), their instructional **practices** (RQ4) and the corresponding **outcomes for students** (RQ5).

This approach provides a holistic understanding of the factors that contribute to the design and implementation of effective teacher training interventions, highlighting how these interventions improve teachers' knowledge and motivation, foster improved instructional practices, and ultimately support positive student learning outcomes.

The findings for the *first research question* highlight several key characteristics and trends within teacher PDC training interventions, particularly in their structure and design. The prevalence of the **TPACK framework as a foundational model** across these interventions underscores its value in addressing the intersection of content, pedagogy, and technology, especially for STEM fields where technological content knowledge (TCK) and technological pedagogical content knowledge (TPCK) are uniquely crucial (Huang et al., 2022). The **greater focus on pre-service teachers** in these interventions underscores a trend towards early PDC development. The **variation in intervention formats**—ranging from short- to long-term durations and incorporating online, face-to-face, blended, and hybrid modes—may reflect an effort to adapt PDC training to the diverse learning preferences and time constraints of teachers**. Blended models, in particular, appear promising** as they allow for a balance between structured support and independent practice, accommodating teachers' schedules while providing both theoretical and hands-on learning opportunities.

With regard to the *second research question* addressing **key practices employed** in teacher PDC training interventions, reflection and self-evaluation stood out as the most frequently utilised practices in teacher PDC training, followed by hands-on learning, lesson planning and design sessions, and instruction and rehearsal/field experience, which reflect the **growing emphasis on practical, experience-based learning in teacher PDC training interventions**. While this deliverable seeks to identify the most effective training methods and key practices for enhancing teachers' PDC, most included studies, as noted in previous umbrella reviews (e.g., Wohlfart and Wagner, 2023), offer limited data on this aspect. Only **a few studies directly compared different key practices, reporting no significant differences** (e.g., Wilson et al., 2020; Wilson, 2023). However, Kay (2006) suggests that combining multiple training strategies may have a greater impact on teachers' ability to use technology effectively. This is in line with the **I/M/T/P framework** (insights, motivation, techniques, and practice) developed by Sims and colleagues (2023), which suggests that training is more effective if it addresses all four purposes of professional development. This indicates that **integrating a variety of training strategies** could lead to better outcomes in upskilling teachers for classroom technology use.

As for the *third research question,* our findings suggest that PDC interventions positively impact knowledge and motivation essential for digital integration, particularly **effective in enhancing PK and CK, although TK remains challenging.** This highlights a need for targeted support emphasising practical digital skills and continuous development, as TK requires ongoing adaptation to rapidly changing tools and is harder to integrate into standard training. **Longer interventions designed with collaborative approaches in a blended mode tend to yield stronger PDC outcomes** for teachers in general (Atmacasoy and Aksu, 2018; Ning et al., 2022). However, pre-service teachers typically benefit more from the training than in-service teachers, which might be related to their developmental phase, suggesting a need for tailored programs for in-service teachers.

Regarding the *fourth research question*, this review underscores that teacher training programmes can enhance teachers' ability to integrate technology effectively in their teaching, making instruction more adaptable to students' needs and encouraging dynamic learning environments (Atmacasoy & Aksu, 2018; González et al., 2024). These impacts on **teaching practices are closely interwoven with other aspects of effective teacher training,** especially the choice of training methods, the role of TPACK and affective factors like teachers' attitudes and confidence. For example, hands-on teaching practices with a learner-centred and collaborative approach were frequently highlighted as effective approaches, as they not only improve teachers' technological knowledge (Huang et al., 2022; Smith et al., 2021) but also increase their confidence in implementing these skills in classroom contexts (Ning et al., 2022; Teo et al., 2021). This suggests that training formats emphasising practical, experience-based learning can positively influence teachers' sense of efficacy, which in turn encourages technology use in classrooms. Additionally, teachers' positive attitudes toward technology—often strengthened through these training programs—appear essential for moving from knowledge acquisition to effective application in real classroom settings (Hennessy et al., 2022; Wang et al., 2018). Nevertheless, some studies suggest that, despite these gains, **translating improved technological knowledge into consistent classroom practice remains a challenge** (Ning et al., 2022), which indicates the need for ongoing support mechanisms. Overall, the findings underscore the interconnectedness of knowledge, practical methods, and affective dispositions in fostering effective teaching practices for technology-rich environments.

As for the *final research question*, we **found a limited number of studies that specifically addressed effects on student outcomes,** with only seven out of 23 providing detailed evidence. While these studies provided valuable insights into subject-specific skills and digital competence, **the results were inconsistent, particularly in the area of academic achievement**. Some studies show improvements in reading comprehension and mathematics, while others report minimal or non-significant changes in subjects like biology and maths. This variability underscores **the importance of considering context and implementation in educational strategies.**

6.2 Implications for practice

In order to design effective teacher training programmes that enhance PDC, it's crucial to understand which design elements contribute most significantly to positive outcomes for both teachers and students. Our findings highlight the multifaceted and interrelated nature of design elements on teachers' practices and student outcomes. In this context, Figure 2 summarises the critical design elements that contribute to effective teacher PDC training interventions that result in improved teaching practices and student outcomes.

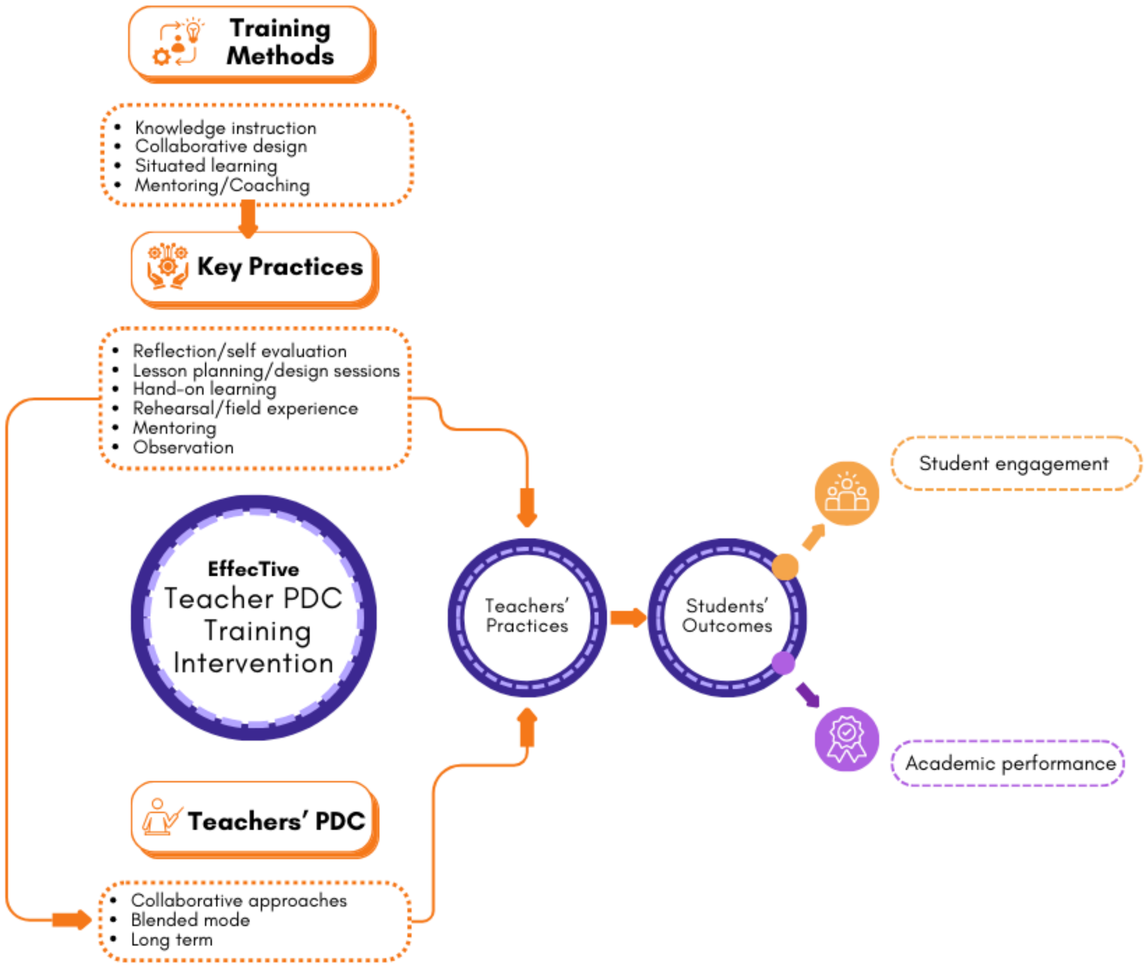

Figure 2. Design Elements of Effective Teacher PDC Training Interventions

It should be noted that the key practices identified in this review align with the four primary methods of our EffecTive framework: knowledge instruction, collaborative design, situated learning, and mentoring/coaching. While this deliverable focuses on general guidelines for evidence-based effective teaching practices, these practices will be integrated into the four training methods and applied in interventions (as detailed in D2.1, Seufert et al., 2024).

Based on the findings of this review, several implications emerge for designing teacher training programmes that enhance PDC and positively affect classroom practices and student outcomes:

- Training programmes should integrate diverse key practices (e.g., reflection, hands-on learning, observation) to help teachers gain practical skills that translate effectively into the classroom. **Combining these key practices** creates a comprehensive training experience that equips teachers with both the skills and confidence needed for effective technology integration in the classroom.
- Programmes that are **longer** and allow teachers to collaborate show a deeper impact on TPACK development, as **collaboration** helps teachers contextualise their digital skills and share strategies.
- **Blended formats** seem to yield better results in terms of satisfaction and confidence. When feasible, blended approaches should be preferred by combining the benefits of online flexibility with in-person interaction to maximise engagement.
- For teacher training to be effective, it is crucial that **teachers are able to apply what they have learnt in real classroom settings**. In this regard, it's important to recognise that teachers' practices are shaped by the design elements of the training itself. Specifically, selecting appropriate training methods, focusing on TPACK (Technological, Pedagogical, and Content Knowledge), and nurturing positive affective factors like teachers' attitudes and confidence are essential for successful outcomes. Addressing these areas together helps to create a holistic training approach that reinforces teaching practices while supporting teachers' PDC.

6.3 Study limitations and implications for future research

This study has some **limitations** that should be acknowledged. First, the broad aim of providing a comprehensive account of effective teacher PDC training interventions resulted in considerable variability between the included studies, which may have affected the consistency of the findings. Differences in the measurement instruments used across studies make it challenging to directly compare results, potentially impacting the overall synthesis of the findings. The included studies may also primarily reflect interventions from specific educational settings or regions, which limits the generalisability of the findings to other contexts or countries with different educational structures and resources. Second, the inclusion and exclusion of articles involved subjective judgements, potentially introducing selection bias. Besides, studies with positive findings are more likely to be published, which may lead to an over-representation of successful interventions and limit the understanding of potentially ineffective approaches to PDC training. Third, we did not conduct a quality appraisal of the systematic literature reviews included, which may affect the reliability of certain findings. Finally, although identifying effective design elements for PDC interventions was a primary aim, these elements were not sufficiently and clearly described, which may hinder the practical applicability of the findings.

In light of these limitations, **future studies could focus on several key areas** to deepen our understanding of effective PDC interventions. Comparative studies evaluating the effectiveness of different PDC interventions in controlled settings would provide valuable insights, particularly into which design elements produce the best results under which circumstances. In addition, as our review found that most studies focused on short-term interventions and targeted pre-service teachers, examining **long-term interventions, including in-service teachers**, could provide a deeper understanding of the impact of these training interventions. Furthermore, while our review found gains in technological knowledge, these were not consistently translated into **practical application in the classroom**. Future studies should prioritise investigating how PDC interventions affect teachers' ability to apply these skills meaningfully in classroom settings, rather than just improving knowledge and perceptions. Finally, given the limited evidence of direct improvements in students' subject matter knowledge and digital competence, future research should emphasise evaluating the impact of teacher training interventions on these **student outcomes** to clarify their broader educational value.

7 Conclusion

In this umbrella review, we aimed to identify effective design elements in teacher training interventions and their impact on both teachers' PDC and student learning outcomes. Evidence suggests that **long-term, collaborative, and blended learning approaches are particularly effective in building teachers' TPACK**, especially among pre-service teachers, by fostering a deeper contextual understanding and practical application of digital tools. Additionally, **affective factors,** such as teachers' confidence and attitudes toward technology, play a crucial role in successful integration. Key practices like **reflection, hands-on learning, mentoring, and observation** are essential in translating knowledge into classroom practices. **Integrating a variety of these practices within training could yield even stronger outcomes** in upskilling teachers' PDC. While these interventions show significant promise, limitations remain in the consistency of the outcomes. Further research is needed to refine these findings and explore how diverse training designs can contribute to improvements in both teaching practices and student learning outcomes.

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