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Preparing preservice teachers to teach with digital technologies: An update of effective SQD-strategies

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ABSTRACT

This systematic review responds to the critical need to equip preservice teachers with the competencies to use technologies within an increasingly digital educational landscape. Given the fact that new ways to learn digitally are constantly emerging, new strategies are needed to support future teachers' digital practices in a different context. This replication study builds upon the Synthesis of Qualitative Data (SQD) model, offering an updated synthesis of effective strategies. Using the PRISMA-methodology, the study critically analyses qualitative evidence from the past 12 years, identifying both persisting and emerging strategies for preservice teacher preparation in the digital age. Findings from the updated SQD-model (SQD2) introduce new themes, including "Digital Identity", "Instructional Design Models", and "Affective Dimensions." These new themes complement the original SQD-model by addressing diverse experiences and technology-specific pedagogical approaches. The discussion section explores the implications and practical applications of these findings, highlighting pathways to enhance digital competency in preservice teacher education.

1. Introduction

Developing digital competencies is a crucial aspect of preservice teacher education (Andreasen et al., 2022; Tondeur, Howard, & Yang, 2021). These competencies are essential not only for integrating digital tools into teaching and learning but also for ensuring future teachers to navigate continuous digital change in education (OECD, 2019). Yet, most studies continue to show that preservice and beginning teachers feel they are not well prepared to effectively use digital technologies in their practice (e.g., Moorhouse, 2021; Reisoğlu & Çebi, 2020; Tondeur, Pareja Roblin, van Braak, Voogt, & Prestridge, 2017). To explore how preservice teachers' digital competencies are developed, many empirical studies (e.g., Buchner & Hofmann, 2022; Hsu & Lin, 2020) have drawn on effective strategies identified in the Tondeur et al. (2012) Synthesis of Qualitative Data (SQD) model.

More than a decade after the original SQD-model's publication, and given rapid change in the field, it has become essential to update the evidence on these strategies for developing preservice teachers' digital competencies. There have been significant changes in digital technology use in schools since COVID-19 lockdowns and changes in practice from ongoing school digitization efforts. As a

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consequence, ongoing technological changes and emerging technologies, such as artificial intelligence (AI), virtual and augmented reality, and other digital learning platforms have continued to shape and change the educational landscape (Emejulu & McGregor, 2019). These trends further underscore the need for teachers to have strong competencies in integrating digital technologies in teaching and learning practices (e.g. Schleicher, 2020). Thus, there remains an ongoing challenge to effectively guiding preservice teachers' development of digital competencies (Basilotta-Gómez-Pablos et al., 2022) .

We argue that new and more targeted strategies are required to support future teachers' digital practices. Therefore, the main goal of this study is to expand upon effective strategies for digital competence identified in the original SQD-model. To meet this objective, we replicated the systematic review of qualitative evidence conducted by Tondeur et al. (2012), employing a similar methodology. Before presenting the study's findings, we first present the conceptualization of digital competence to highlight its critical role in teacher training. We then introduce existing frameworks and strategies for preparing preservice teachers to use technology in education. This is followed by an overview of the systematic review study design. We conclude by discussing how the updated model can enhance preservice teacher training.

2. Background

To address preservice teachers' digital competencies, teacher training institutions need to incorporate a range of strategies to them for teaching with digital technologies and ongoing technological change (Valtonen, Sointu, Kukkonen, Mäkitalo, Hoang et al., 2019). However, teaching with digital technologies requires both technical skills and specific pedagogical approaches (Tondeur et al., 2023; Starkey, 2020). Research has shown that this is a complex process, resulting from combinations of strategies that depend on the profile of the individual preservice teacher (Tondeur et al., 2021). In the following sections, we address the nature of teachers' digital competence and the ongoing issue of how it is developed in preservice teachers.

2.1. *Teachers' digital competency*

The demand for teachers equipped with digital competencies grows continuously. Teachers must be able to use digital technologies effectively in teaching and learning to enhance learning outcomes and foster students' digital skills (Reisoğlu & Çebi, 2020; Siddiq et al., 2023). While "skills" typically refer to technical proficiency, "competencies" are conceptualised as the integrated, functional use of knowledge, skills, and attitudes (Falloon, 2020). Consequently, digital skills are considered a subset of broader digital competencies. However, definitions about digital competencies vary widely due to the rapid pace of technological advancement (Bilbao Aiastui, Arruti Gómez, & Carballedo Morillo, 2021; Starkey, 2020). In response, many organisations have developed new frameworks outlining the digital competencies that (preservice) teachers should meet, such as the HediCom framework (Tondeur et al., 2023) and DigCompEdu (Vuorikari et al., 2022).

As definitions of digital competencies evolve, a core aspect remains: the effective use of technologies to meet various demands, whether social, professional, or educational. Here, we adopt the European Union's (2018), p. 20 comprehensive definition, which views digital competence as the confident, critical, and responsible use of, and engagement with, digital technologies for learning, work, and societal participation. This includes skills in information and data literacy, communication and collaboration, media

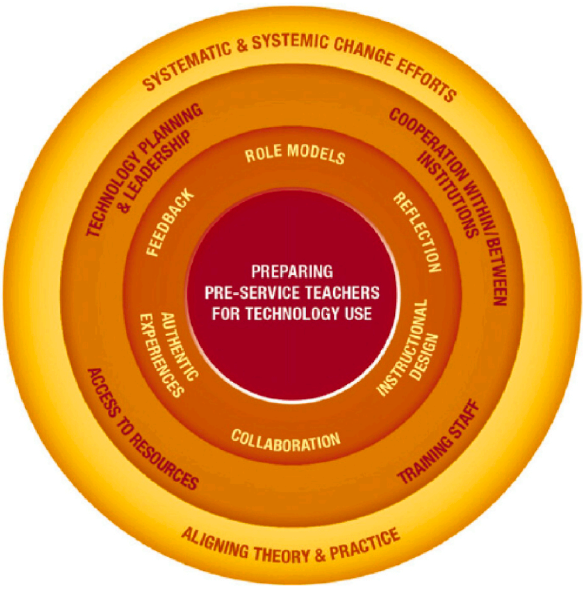

Fig. 1. Synthesis of Qualitative Data (SQD) model (Tondeur et al., 2012).

literacy, digital content creation (including programming), safety (encompassing digital well-being and cybersecurity), intellectual property considerations, problem-solving, and critical thinking (Tondeur, Aesaert, Prestridge, & Consuegra, 2018; Starkey, 2020). Therefore, it is essential that preservice teachers encounter positive uses of digital technologies to build confidence and foster constructive attitudes toward their digital practice. Despite this detailed definition, questions remain around how to foster these competencies in teacher education. This leads us to the following section.

2.2. Digital competence strategies

In building preservice teachers' digital competencies, research indicates that teacher training institutions typically emphasise technical aspects, while overlooking necessary pedagogical support (Scherer et al., 2021; Starkey, 2020). This imbalance is problematic, as technical skills alone are insufficient; training should also encompass pedagogical, social, and well-being competencies. As noted, a range of strategies are necessary in preparing preservice teachers to integrate digital technologies in their future practice (Buchner & Hofmann, 2022; Hsu & Lin, 2020). Tondeur et al.'s (2012) Synthesis of Qualitative Data (SQD) identified such strategies, organised across three levels (see Fig. 1). The outer level emphasises systemic and systematic change efforts, alongside the alignment of theory and practice. The second level focuses on institutional factors, such as technology planning and leadership, staff training, resource access, and inter-institutional cooperation. The innermost level includes six micro-level strategies: (1) role models, (2) reflection on digital technology's role, (3) design-based digital technology use, (4) collaboration, (5) scaffolded authentic experiences, and (6) continuous feedback. These strategies collectively form the SQD model (Tondeur et al., 2012). The systematic review of SQD strategies underscores the importance of addressing both individual and combined strategies to effectively prepare preservice teachers for digital competency (Hsu & Lin, 2020; Tondeur et al., 2021). As stated above, Howard et al.'s (2021) analysis of these combined strategies reveals complex interrelationships essential for the successful development of digital competencies in preservice teachers.

After the SQD model was developed, the next step was to evaluate the extent to which these strategies are implemented by teacher training institutions and to investigate their impact on preservice teachers' ICT competencies (Buchner & Hofmann, 2022; Hsu & Lin, 2020). For instance, Buchner and Hofmann (2022) demonstrated that learning designs based on the SQD model's micro-level strategies are particularly effective in fostering teachers' competencies related to augmented and virtual reality. They designed a four-week training module for preservice teachers specifically aimed at these competencies. Similarly, Hsu and Lin (2020) explored the influence of SQD-strategies on participants' perceived technology knowledge and attitudes toward adopting technology in education. Their findings indicated that, among the six SQD-strategies, reflection and instructional design had the most substantial positive impact.

Further, there is a scarcity of empirical studies examining the combined impact of support for preservice teachers related to their individual ICT-profiles, such as attitudes toward ICT or previous experience with technology. This relationship is particularly significant, as research has shown that preservice teachers' ICT-profiles strongly influence their use of educational technologies (e.g., Teo, Milutinović, & Zhou, 2016). Anderson and Maninger (2007) argue that cultivating these ICT-related characteristics during teacher preparation programs is essential (see also Tondeur et al., 2018). These findings suggest that the integration of digital technologies in teacher education is more complex, constrained, and nuanced than what national curricula typically outline (Andreasen et al., 2022; Tondeur et al., 2021).

2.3. The present study: a new evidence-based model to inform teacher education

The question of how best to prepare preservice teachers for integrating educational technology remains open. As discussed, developing competencies to use digital tools in teaching and learning requires a diverse set of strategies within teacher training institutions (cf. Buchner & Hofmann, 2022), encompassing both technical skills and pedagogical approaches (Brianza, Schmid, Tondeur, & Petko, 2024). In addition to a skill and pedagogical based focus, it is also important to regard the attitudes and beliefs of teaching professionals towards digital technologies because they influence the actions of individuals and play an important role in the learning process Hämäläinen et al. (2021). Clearly, this process is complex, as the optimal combination of strategies depends on each teacher's unique profile (Tondeur et al., 2023). Research shows that preservice and novice teachers often feel inadequately prepared to use digital technology effectively in their practice (e.g., Moorhouse, 2021). Tondeur et al. (2012) SQD-model identified strategies for fostering digital competencies in preservice teachers; however, this review was published over a decade ago. Therefore, the main aim of this study is to identify recent advances in effective digital competence strategies for teacher education. To achieve this, we replicated Tondeur et al.'s (2012) systematic review of qualitative data.

3. Research method

3.1. Meta-aggregation of qualitative studies

In this study, we employed a systematic review method to locate, critically evaluate, aggregate, and synthesise qualitative studies (cf. Flemming & Noyes, 2021) on effective strategies for developing preservice teachers' digital competencies. The review team comprised the four authors, each experienced in research on teacher education and technology use in education. Adopting the PRISMA methodology, the team identified relevant empirical studies (Page et al., 2021). Using a meta-aggregative approach, developed by the Joanna Briggs Institute (http://joannabriggs.org), the team extracted and synthesised qualitative data through meta-aggregation (cf. Hannes & Lockwood, 2011). This approach provided valuable insights into digital competence strategies to effectively train preservice teachers. The growing volume of qualitative research on preservice training enabled us to aggregate findings and synthesise insights from individual studies. This meta-aggregative approach to extracting and synthesising qualitative data emphasises (1) the complexity of interpretive understandings of phenomena, (2) a transparent synthesis process, and (3) the creation of practical, useable synthesised statements (see also Tondeur et al., 2017, 2019). The advantage of such a systematic review is that it produces a holistic view of the field. More specifically, this review of qualitative research was used to synthesise the evidence into how and why specific strategies can be used to better prepare pre-service teachers to integrate technology into their future practice."

3.2. Search strategy and inclusion criteria

This review study applied a fixed set of inclusion criteria. First, the research had to be empirical and based on a qualitative methodology. Additionally, the focus needed to be on teacher training, specifically targeting the development of competencies for integrating digital technologies in education. Studies were identified through a comprehensive search of full empirical manuscripts in the Web of Science database. Publications such as concept papers, reviews, or editorials were excluded. Key search terms included "teacher education," "pre-service education," "student teacher*," "pre-service teacher*," "prospective teacher*," "trainee teacher*," "teacher educator*," and their combinations. These terms were further paired with keywords such as "technology," "IT," "information technology," "ICT," "information communication technology," and "computer*." The search was restricted to empirical studies published in English between 2012 and 2024.

The initial search yielded 267 potentially relevant journal articles. The selection process is summarised in Fig. 2. During the first screening, two members of the review team independently examined the titles and abstracts of the identified manuscripts. Articles were excluded if they did not sufficiently focus on the topic. For instance, some studies addressed teacher education in general but lacked a clear emphasis on preparing teachers for technology integration. Others explored student teachers' perceptions of technology use but did not examine the training that shaped those perceptions. These exclusions ensured that the review focused solely on studies aligned with the research objective.

Following the initial screening, 63 studies were selected for further analysis (Fig. 2). In the next phase, the Joanna Briggs Institute checklist was applied to assess the quality of the 50 manuscripts that were available for evaluation. This quality appraisal process determined which studies would ultimately be included in the synthesis. The results of the appraisal are detailed in Table 1.

As shown in Table 1, 28 studies met the criteria and were included in the current review for analysis. These articles were published

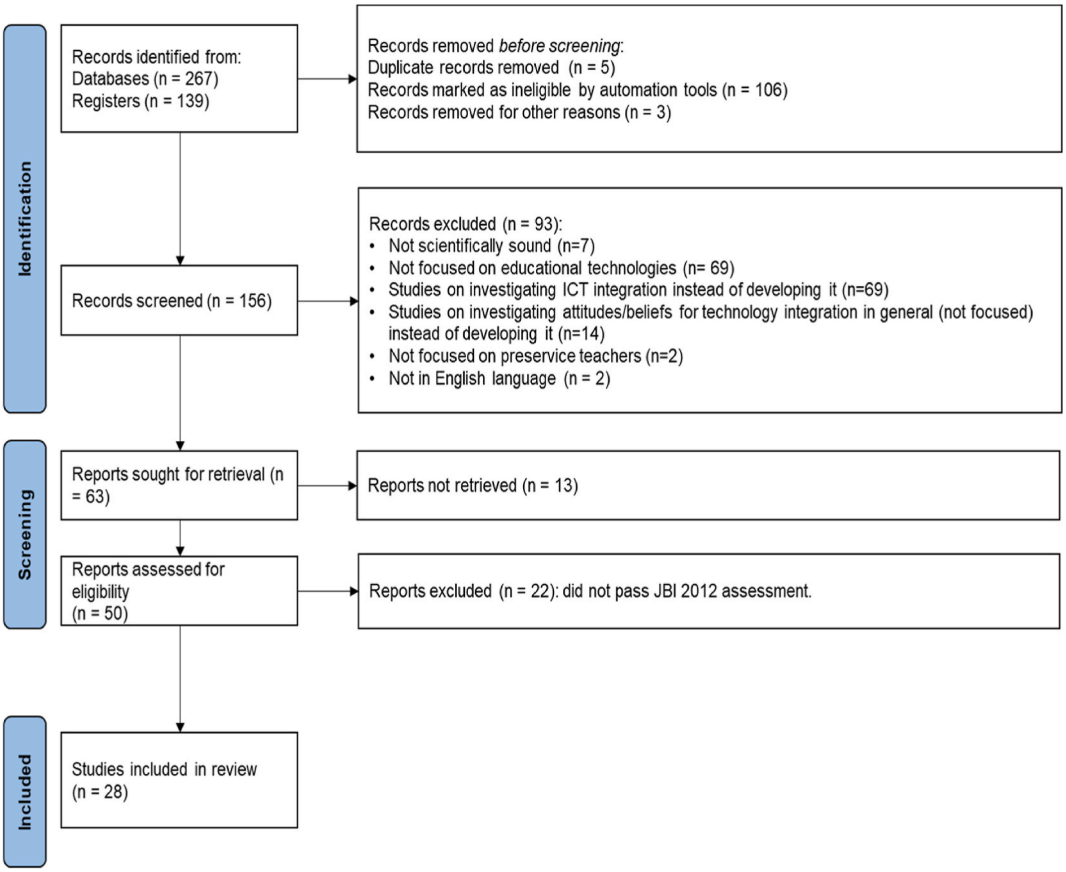

Fig. 2. Selection process (based on Page et al., 2021).

Table 1
Quality criteria and results (based on JBI 2012 checklist).

Question	Yes	No	Unclear
1. Is this study qualitative research?	45	3	2
2. Are the research questions clearly stated?	42	4	4
3. Is the qualitative approach clearly justified?	32	4	14
4. Is the approach appropriate for the research question?	43	3	4
5. Is the study context clearly described?	42	3	5
6. Is the role of the researcher clearly described?	20	6	24
7. Is the sampling strategy appropriate for the research question?	36	3	11
8. Is the data collection method appropriate to the research question?	44	3	3
9. Is the method of analysis clearly described?	40	4	6
10. Is the analysis appropriate for the research question?	41	3	6
11. Are the claims made supported by sufficient evidence?	39	3	8
Overall appraisal of the 32 manuscripts considering JBI 2012 scores:			
Include: 28 Exclude: 22			

across 20 journals and conducted in 15 different countries. Notably, seven studies originated from Turkey, five from the USA, two from Taiwan, with the remaining studies representing various other countries worldwide. Detailed information about each of the selected studies is provided in Appendix A.

3.3. Analysis

As outlined above, a meta-aggregative approach was employed to review the qualitative evidence, following the three-step process described by Hannes and Lockwood (2011). In the first step, findings were extracted from the 28 selected studies. These findings were aggregated to identify a list of emerging common themes (see Figs. 3–8). To ensure fidelity to the primary studies, the original descriptions from the results and discussion sections of the selected articles were used. This required repeatedly revisiting the original data to verify, refine, or expand interpretations. In the second step, the extracted findings were categorised to identify patterns and themes that spanned across the studies and held similar meanings. Finally, in the third step, the categories were synthesised to produce a set of overarching findings. This process resulted in six synthesised statements that highlight the key effective practices identified in the literature. These statements offer actionable recommendations for practitioners, policymakers, and researchers to enhance technology integration in education. The findings were aggregated and synthesised independently by two researchers, and any disagreements were resolved through collaborative discussion among all four authors. A detailed overview of the coding process is provided in Fig. 2, with the codebook available in Appendix B. The results section describes each category and synthesised statement, accompanied by examples. Additionally, Appendix B presents the emerging themes and categories for each study.

4. Results

Analysis revealed several key themes essential for preparing preservice teachers for digital technology integration, in their future practice. Findings are presented in two sections: (1) key strategies specifically targeting the training of preservice teachers, and (2) broader strategies addressing strategies at the institutional level. Overall, 28 sub-categories (SC) were aggregated into 10 categories (C), which were further consolidated into six synthesised statements (see Figs. 3–8). Appendix B provides an overview of the (sub-) categories and their alignment with the individual studies. These themes informed the development of synthesised statements outlining effective strategies for training preservice teachers in the integration of digital technologies.

4.1. Strategies to train preservice teachers

4.1.1. Synthesis 1: Familiarisation

The first synthesis addresses “Familiarisation”. Analysis of the qualitative evidence resulting in two main categories within this synthesis: "Modelling" (C1) and "Exploration" (C2). The synthesised statement posits that *"familiarisation with new technologies through modelling and exploration is necessary for preservice teachers to experience the potential of emerging technologies in education"* (Fig. 3).

Familiarisation is an important early step in introducing digital technologies to preservice teachers. Two main approaches were identified here: modelling and exploration. The first category, *“Modelling”* (C1), emerged as a key theme in 18 studies and encompasses three sub-categories: *“Role models”* (SC1, $n = 15$ studies), *“Pedagogical approaches”* (SC2, in 4 studies), and *“Gamification”* (SC3, $n = 4$ studies). The findings consistently emphasised the importance of modelling in motivating preservice teachers to integrate digital technologies into their own teaching practice. Eutsler (2022) illustrated this through teacher educators demonstration of how to use various iPad apps. After, preservice teachers were invited to conduct a shared reading lesson using an app of their choice. Approximately 60% of the preservice teachers opted for the same app demonstrated by the educator. One preservice teacher reflected, *“I really liked the iPad workshops … [they] gave me insight into an aspect of teaching that I had never considered before”* (Eutsler, 2022, p. 338). Similarly, Liu et al. (2015) observed that preservice teachers often mirrored mentors’ approaches to technology integration in their

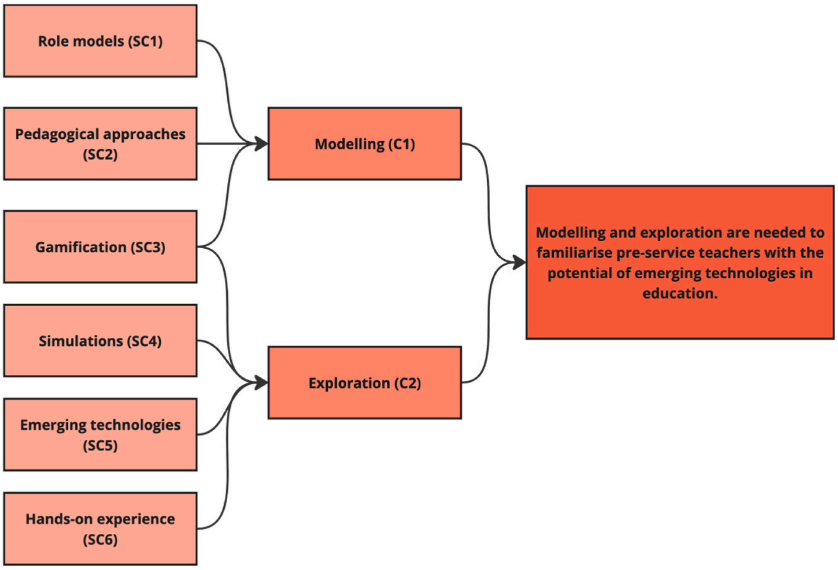

Fig. 3. Categories contributing to synthesis 1.

own activities. These findings highlight modelling as a crucial component in shaping preservice teachers' selection, use, and experiences with digital technologies.

A specific application of modelling is *"Pedagogical approaches"* (SC2), such as online and blended learning. For example, Şen and Hava's (2020) demonstrated that modelling the flipped classroom approach for third-year preservice teachers led to increased perceptions of responsibility for their own learning. It also enhanced their understanding of the method and its practical implementation in their future teaching. By experiencing the flipped learning approach firsthand, preservice teachers gained critical insights into its relevance and potential application in their practice. Additionally, they felt incorporating games into videos made learning more engaging and effective. This belief was demonstrated through Kahoot quizzes at the end of videos. These not only increased enjoyment but also enhanced learning outcomes (Şen & Hava, 2020). This finding also aligns with the sub-category *"Gamification"* (SC3), given that gamification is a particular approach to teaching and learning commonly found in digital technologies. Gönen's (2019) study in Turkey included diaries and focus group interviews with preservice language teachers, after using gamified digital technologies such as Popplet, Glogster, Quibblo and Go Animate. Results revealed that observing effective examples of gamification fostered positive attitudes toward its use. However, authors highlighted the importance of providing preservice teachers opportunities to explore and practise these strategies themselves. Together, these findings underscore the interconnection of modelling and experiential learning in shaping preservice teachers' competencies.

Building on this argument, the second category, "*Exploration*" (C2), was identified in 21 studies. In addition to the inclusion of "*Gamification*" (SC3) within the category of "Exploration", three other subcategories were identified: "*Simulations*" (SC4, $n = 5$ studies), "*Emerging Technologies*" (SC5, $n = 3$ studies), and "*Hands-on Experience*" with digital technologies (SC6, $n = 17$ studies), as exemplified by comments such as, "*exploring the components before moving on to apply this knowledge with Scratch and the Lego WeDo materials, and then later with the children in the classroom experience*" (Butler & Leahy, 2021). Again, the findings highlight the value of combining strategies. For instance, Schina et al. (2021) investigated preservice teachers' acceptance of and self-efficacy with educational robotics during a university course. During the course, participants engaged in hands-on experiences with various educational robotics tools, linking "Emerging Technologies" (SC5) with "Hands-on Experience" (SC6). Preservice teachers described these sessions as "useful" and "practical," noting that they "*saw first-hand how to integrate robotics into educational contexts*" (p. 11). These hands-on experiences were particularly valuable as participants also expressed that "*during the bachelor's degree we did not experiment enough with digital technologies in education*" (Schina et al., 2021, p. 11). However, when direct hands-on opportunities are unavailable, "Simulations" (SC4) offer an effective alternative. For example, Orsini-Jones (2023) described a preservice teacher's reflection on completing a collaborative lesson plan design within a teacher program called Virtual Exchange as a Transformational Third Space for English Language Teacher (ViVEXELT). Hands-on experience is particularly useful where students have no prior experience, such as with robotics. Also, it models to them how to incorporate experience into their own practice, for their future students.

4.1.2. Synthesis 2: Reflective practice

The synthesis of reflective practice draws on qualitative data from 21 studies and includes four sub-categories: *"Digital Pedagogies"* (SC7, *n* = 14), *"Research"* (SC8), *"Teacher Identity"* (SC9, *n* = 10), and *"Technology Scaffolding"* (SC10). Based on evidence from these sub-categories, Synthesis 2 emphasises that "*preservice teachers must critically reflect on and engage with both the potential and limitations of technology in education*" (Fig. 4). This reflective process is essential for fostering deeper understanding and informed decision-making in their future teaching practices.

"Digital Pedagogies" (SC7) highlighting the reflective practices of preservice teachers, as they considered their training experiences and outcomes. Butler and Leahy's (2021) mixed-method study on computational thinking and robotics illustrates this theme. Results from their study demonstrated how preservice teachers applied new pedagogical approaches introduced in workshops to their classroom practice. One participant noted, *"this has been a very reflective process in which I have considered my own experiences as well as learning from the pupil's experiences"* (p. 1073). Overall, students reported that reflection lessons after their classroom experiences deepened their understanding. Similarly, *"Research"* (SC8) played a critical role in fostering preservice teachers' reflective practices. Typically, research tasks involved producing tangible outcomes, such as essays or presentations (e.g., Umutlu, 2022). In Genç's (2019) study, preservice teachers were expected to investigate and apply a range of techniques and perspectives to create digital stories for science teaching. Participants noted that examining research studies helped them identify solutions to challenges in designing science lessons, demonstrating how engaging with research can enhance reflective practice and inform teaching strategies. This suggests that incorporating research offers a valuable strategy for bridging the gap between theory and practice (cf. Butler & Leahy, 2021; Eutsler, 2022).

Another form of reflection is evident in the development of preservice teachers' *"Teacher Identity"* (SC9). Specifically, reflecting on their role in relation to digital technologies was closely tied to their evolving educational practice. For instance, Moran et al.'s (2023) study explored how preservice teachers grappled with the concepts of 'learning' and 'play' within their conception of teaching and learning. One participant reflected: *"I felt like a lot of it [what they implemented in the elementary classroom] is enhancing their learning. Are they playing? And so, I feel like through the program and throughout my placement, being able to integrate that technology … I think that is just something I grew in[to] because when I started out, I felt like that was a very fine line, so that was something I struggled with."* (Moran et al., 2023, p. 7). The student's comments illustrate how their experiences with digital technologies during their placement helped them to better understand and internalise their perspective on the role of technology in learning. This reflective process was key to shaping their emerging teacher identity and clarifying their stance on integrating digital technologies into educational practice.

An additional emerging strategy within "*Reflective Practice*" is *"Technology Scaffolding"* (SC10), with a specific focus on the use of artificial intelligence (AI). In Halonen et al.'s (2023) study, physics preservice teachers engaged with AI-generated word clouds to analyse and reflect on their group discussions about lesson planning. While some students initially found the AI tool challenging to use, as reflected in comments like, *"Oh no?", "It never works when we want it to"* (Halonen et al., 2023, p. 12), they persisted in utilising the tool. This perseverance enabled them to explore their use collaboratively and reflectively. The AI-generated word clouds provided a

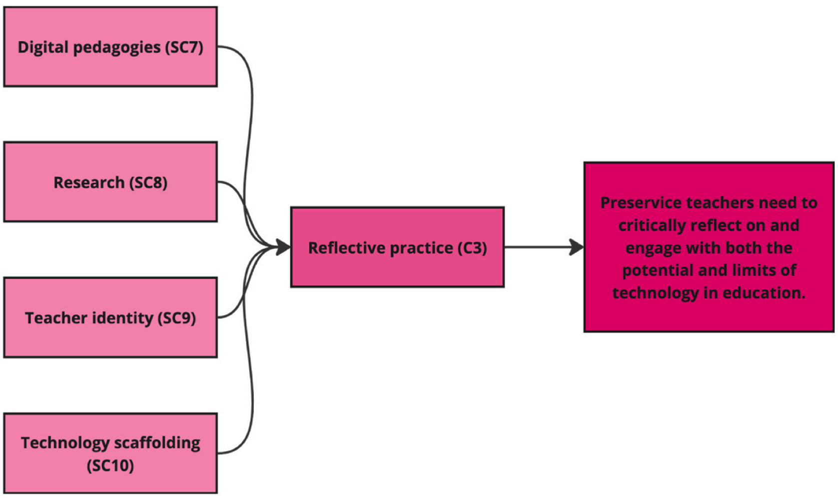

Fig. 4. Categories contributing to synthesis 2.

novel and effective way to support group reflection and co-creation. With such technologies becoming increasingly available in education, their potential to enhance reflective practice is promising.

4.1.3. Synthesis 3: Collaborative design

From the six sub-categories *"Group work"* (SC11, $n = 19$), *"Partnership"* (SC12, $n = 7$), *"Digital Communication"* (SC13, $n = 6$), *"Instructional design models"* (SC14, $n = 23$), *"Design Activities"* (SC15, $n = 19$) and "Constructive alignment" (SC16, $n = 6$), we developed two main categories: *"Collaboration"* (C4) and *"Designing"* (C5). Together, these categories inform the *"Collaborative design"* synthesis, which underscores that *"a range of collaborative design activities are necessary to train preservice teachers in creating technology-rich lesson plans"* (Fig. 5).

The first category, "Collaboration" (C4), was identified in 20 studies and comprises three sub-categories: "Group Work" (SC11), "Partnership" (SC12), and "Digital Communication" (SC13). All these sub-categories highlight the importance of collaboration among preservice teachers. The sub-category "*Partnership*" - found in seven studies (e.g., Liu et al., 2015; Moran et al., 2023) - focuses on creating connections between preservice teachers, their mentors, and the broader community to share expertise. For instance, in Moran et al.'s (2023) study, one student reflected: *"Partnering with my mentor was a very empowering experience … it involved a lot of discussions and idea pitches and trial and error … in order to make sure that the integration of technology not only enhanced the lesson, but also kept student learning as a central focus"* (p. 8). This highlights how collaborative partnerships foster deeper engagement with technology integration. Similarly, "*Digital Communication*" emerged as an essential element of collaboration. In Goktas and Demirel's (2012) study, preservice teachers created blogs on the topic of 'our country's resources,' using maps and videos to visually enrich their content and communicate their positions. Çevik, Çelik, & Haşlaman (2014) found that Facebook was a convenient platform for preservice teachers to share reflections and discuss pedagogical aspects of constructivism. These subcategories illustrate two distinct forms of collaboration: collaboration among students and with mentors or external partners. In both cases, the ability to communicate effectively about digital learning and design as part of the collaborative process is critical.

"Digital Communication" (SC13) was also closely connected to the category *"Designing"* (C5), which encompasses three other subcategories: *"Instructional Design Models"* (SC14), *"Design Activities"* (SC15) and *"Constructive alignment"* (SC16). Together, these subcategories highlight the critical role of design in preparing preservice teachers for technology integration. Instructional design models provide preservice teachers with frameworks and tools for pedagogical guidance. Many of the studies in this sub-category focused on the Technological Pedagogical Content Knowledge (TPACK) framework (e.g., Goktas & Demirel, 2012; Gonen, 2019). These studies emphasised the importance of preservice teachers understanding TPACK components and their interplay in instructional design. For instance, Liu et al. (2015) demonstrated how mentor teachers provided guidance on pedagogical knowledge and facilitated interactions with skilled peers. This support enabled preservice teachers to repeatedly practise applying Technological Content Knowledge (TCK) and Technological Pedagogical Knowledge (TPK), which fostered their professional growth and strengthened their

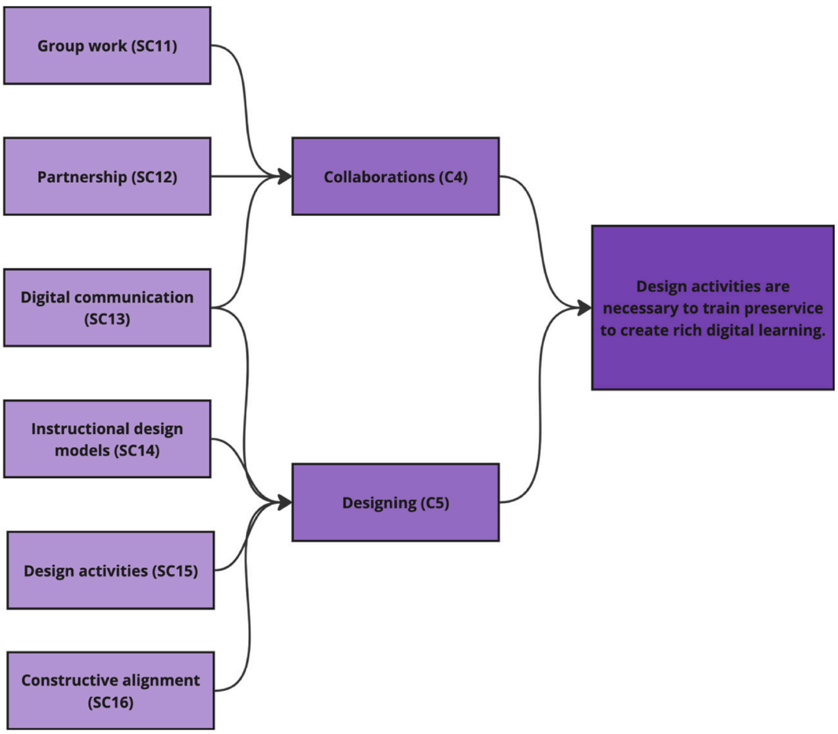

Fig. 5. Categories contributing to synthesis 3.

ability to integrate technology effectively into their teaching.

Based on the overall qualitative evidence, *"Design Activities"* (SC15) emerged as a significant theme in 19 of the 28 studies (e.g., Crosthwaite & Wijaya, 2021). The study by Çevik et al. (2014) exemplifies the interconnection between design activities and the TPACK framework. In this study, preservice teachers not only designed and implemented teaching and learning activities but also explored the interplay between novel technologies and pedagogical approaches. According to the authors, this type of design activity enabled preservice teachers to integrate innovative technologies and pedagogies effectively into their professional practice.

Additionally, design activities offer preservice teachers opportunities to reflect on the alignment of their instructional designs. *"Constructive Alignment"* (SC16) highlighted the responsibility of preservice teachers to align digital technology use with expected learning outcomes, as well as state and national learning standards.emerged (e.g., Lubin & Ge, 2012; Şen & Hava, 2020), For example, in Eutsler's (2022) study, preservice teachers were guided on how apps could support literacy learning while meeting state and national standards. One participant noted, *"I really enjoyed this experience. I learned a lot of different ways that we can use iPads in the classroom in order to teach children literacy"* (Eutsler, 2022, p. 338). These findings naturally lead to the next section.

4.1.4. Synthesis 4: A cycle of authentic teaching

Within the context of designing lessons, two closely related categories -*"Authentic Experiences"* and *"Feedback"* - comprise five subcategories: *"Real World"* (SC16, $n = 18$), *"Teaching Experiences"* (SC17, $n = 6$), *"Instructional Guidance"* (SC18, $n = 3$), *"Pedagogical Reasoning"* (SC19, $n = 19$), and *"Reflection on Designs"* (SC20, $n = 21$). These findings highlight the interconnected nature of authentic experiences and the feedback provided to preservice teachers. Together, they underscore the critical role of a continuous cycle of authentic experiences and feedback in supporting preservice teachers to develop their digital competencies. This relationship was captured in a synthesis statement: *A cycle of authentic experiences and feedback* support *preservice teachers to build their digital practice.* This emphasises the importance of this iterative process of authentic experiences and feedback to support preservice teachers to build their digital practice.

The first category, *"Authentic Experiences"* (C6), was a prominent theme appearing in 23 studies and encompassed four subcategories: *"Real World"* (SC17), *"Teaching Experiences"* (SC18), *"Instructional Guidance"* (SC19), *"Pedagogical Reasoning"* (SC20) and *"Reflection on Designs"* (SC21). These subcategories collectively emphasise the importance of providing preservice teachers with opportunities for authentic teaching experiences using technology. For example, Butler and Leahy (2021) described a real world experience in which preservice teachers taught computational thinking by encouraging children to critically evaluate each block of code, break down problems using decomposition skills, and debug their work. A preservice teacher reflected, *"We realised we needed to work on our questioning"* (pp. 1071–1072), illustrating how such authentic experiences promote both skill development and pedagogical awareness.

Similarly, *"Teaching Experiences"* (SC18) are critical for exposing preservice teachers to diverse strategies and learning environments. The rise of online teaching following the pandemic has made it an essential component of preservice teacher training (see Orsini-Jones, 2023). For instance, one preservice teacher in Lee, Davis, and Li (2022) remarked, *"Since it was my first time completing online micro-teaching, I learned many things about planning a technology-integrated lesson, making an online micro-teaching video, and creating a Google Classroom for my own LMS. Thanks to these experiences, I felt more confident teaching my future students than at the beginning of this semester"* (p. 80). Further, in Çevik et al.'s (2014) study, participants believed the practical experience of using Facebook supported connections between practice and theory. One student explains this connection: *"Thanks to this project, I have met the media (Facebook) I will use in my teaching career. I noticed the importance of giving information to students in different media … I have*

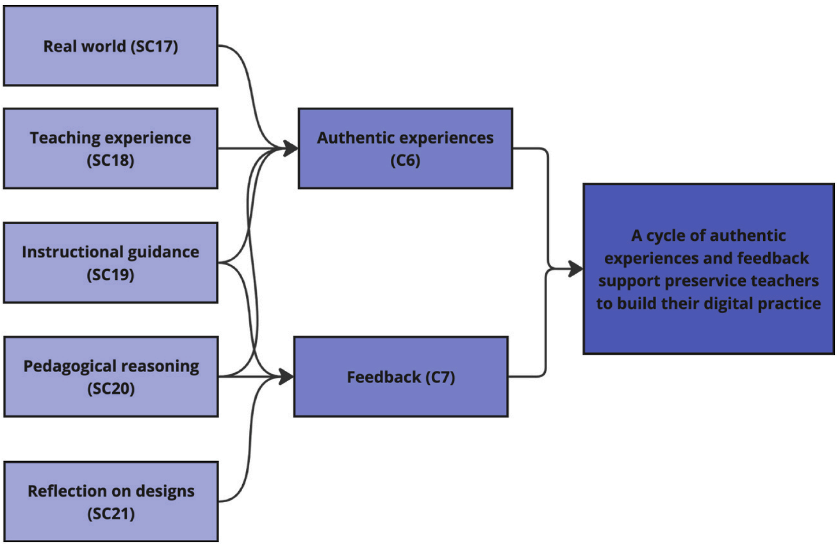

Fig. 6. Categories contributing to synthesis 4.

learned important issues about how I should manage students in distance education and what kind of instructions I should give" (p. 720). These findings highlight the vital role of authentic teaching experiences in building preservice teachers' confidence and understanding of various technology-integrated approaches.

A critical component of *"Authentic Experiences"* is *"Instructional Guidance"* (SC19) which preservice teachers receive from mentors and peers throughout a design process. For instance, a preservice teacher in Lee, Davis, and Li (2022) study reflected, *"While observing peer teaching videos, we provided synchronous feedback to each other's micro-teaching videos. It was a unique experience because feedback from peers and the instructor helped me better understand how to do it effectively in the future"* (p. 81). This experience underscores the value of mentor and peer input not only for building confidence but also for enhancing the individual's *"Pedagogical Reasoning"* (SC20). Through this collaborative feedback process, preservice teachers gained a deeper understanding of how to implement technology-integrated approaches effectively in their future teaching practice. These findings highlight that feedback providing instructional guidance is essential for translating authentic experiences into pedagogical insights.

For this dual purpose, the subcategories *"Instructional Guidance"* and *"Pedagogical Reasoning"* are closely linked to both *"Authentic Experiences"* and *"Feedback"*. This relationship highlights the importance of feedback, peer and mentor input, and guidance in stimulating preservice teachers' pedagogical reasoning about integrating theory, practice, and digital technologies. Another important subcategory of *"Feedback"* is *"Reflection on Designs"* (SC21), which encompasses reflecting on course structures and strategies (e.g. Weinhandl et al., 2023; Yilmaz, 2016). Butler and Leahy (2021) highlighted this in their study, where *"Elizabeth refers to the disadvantage of the absence of a human person … She also discusses the extent to which students are more accepting of feedback from a human than from a computer"* (p. 14). Such reflections allow preservice teachers to explore various facets of teaching and learning. For instance, in Eutsler's (2022) study, preservice teachers noted that reflecting on designs provided them with *"insight into an aspect of teaching that I had never considered before."* Similarly, in Gönen's (2019) study, reflection was used to explore how technology could be applied to language learning. One preservice teacher remarked, *"Students generally associated computers and technology with only playing games … showing them ways of using technology for language learning purposes expanded their perspectives."* These findings demonstrate how feedback and reflective practices expand preservice teachers' understanding of teaching with digital technologies, equipping them to design meaningful and effective technology-integrated learning experiences.

4.1.5. *Synthesis 5: Affective dimension*

The synthesis identified three subcategories: *"Attitudes and Beliefs"* (SC22, $n = 9$ studies), *"Emotional Sphere"* (SC23, $n = 17$), and *"Sensitivity to Tech Gaps"* (SC24, $n = 9$). These findings suggest that *affective characteristics should be taken into account when preparing preservice teachers for digital technology use in education.* (see Fig. 7). Importantly, this theme addresses, not specific strategies, but the presence and importance of preservice teachers' affective responses to digital technologies, which mentor teachers should address in their training.

"Attitudes and Beliefs" (C22) emerged as a significant overall theme in nine of the selected studies. For instance, studies such as Diamah et al. (2022) and Halonen et al. (2023) demonstrated that preservice teachers reported changes in attitudes and beliefs toward digital technologies following an intervention or experience. The research consistently highlights that positive beliefs about the integration of digital technologies are a key factor in teachers' adoption and sustained use of digital technologies in their practice (e.g., Goktas & Demirel, 2012; Halonen et al., 2023). Teacher training can include interventions designed to affect attitudes and beliefs (e.g., Diamah et al., 2022; Speer and Eichler, 2022). For example, a preservice teacher in Eutsler's (2022) study reflected, *"I wish this was a*

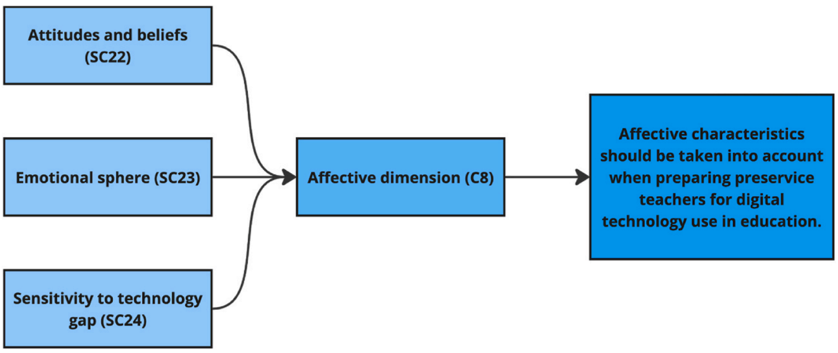

Fig. 7. Categories contributing to synthesis 5.

thing back when I was in elementary/middle school. When studying for these types of tests when I was younger, I would make little connections in my head. But it's super helpful if not only you have a verbal connection, but a visual connection as well" (p. 337). This comment not only highlights a positive experience but also illustrates how it can reinforce the belief that digital technologies hold significant value in enhancing learning.

Positive experiences with digital technologies often generate a favourable affective response, directly connecting to preservice teachers' "*Emotional Sphere*" (SC24). A positive affect not only boosts confidence but also increases the likelihood of ongoing use and further experimentation with digital tools. For instance, Moran et al. (2023) demonstrated how preservice teachers were excited about developing creativity and innovation through digital technologies. One participant reflected, "*I feel better about myself as a teacher that I am doing the right thing, and I feel more confident, being able to be innovative and doing things for my students to benefit them*" (p. 7). Conversely, negative experiences, such as stress or frustration, can discourage preservice teachers from integrating digital technologies into their practice (e.g., Park, 2019; Şen & Hava, 2020). In Şen and Hava's (2020) study on flipped learning with preservice mathematics teachers, several participants expressed negative perceptions that undermined their willingness to adopt the approach in the future. For example, one teacher stated, *"We are accustomed to the traditional method for years. Our teacher has always been at the center. We watch lecture videos, but there is always a gap in our minds,"* while another remarked, *"I think that as there is not an explanation of the course content in the lesson, this model does not have any contributions to us"* (p. 3474). By fostering reflection on both positive and negative emotional responses, training programs can better support preservice teachers in overcoming challenges and building the confidence necessary for technology integration.

Finally, "*Sensitivity to Tech Gaps*" (C24) was often framed in terms of equity issues (e.g., Lee, Davis, & Li, 2022; Nilsson, 2024; Şen & Hava, 2020). This was exemplified in Galway et al.'s (2020) study, where qualitative evidence revealed, "*Some participants struggled with the equity problem and felt that use of specific apps for instructional purposes would mean some students could be marginalised …*" (p. 568). Notably, a sensitivity to tech gaps extends beyond issues of device access. Instead, it encompasses disparities in digital competence (Nilsson, 2024), intercultural awareness (Shin, Choi, Angay-Crowder, & Khote, 2024), and the ability to support students with learning difficulties (Lee, Davis, & Li, 2022). These concerns reflect the challenges of ensuring that all students can effectively engage with new digital technologies.

4.1.6. Synthesis 6: Institutional vision

The final synthesised statement reflects the qualitative evidence aggregated from four sub-categories contributing to two main categories: *"Pedagogical vision"* and *"Group commitment"*. The four sub-categories are: "*Course structure & design*" (SC25, $n = 12$, "*Digital learning & teaching*" (SC26, $n = 13$), "*Collegiality*" (SC27, $n = 7$) and *"Professional learning"* (SC28, $n = 5$). The synthesised finding for this theme is the importance of "*A vision of digital technology use at the institutional level is needed to train teachers for the future of educational technology.*" (Fig. 8).

"*Pedagogical vision*" (C9) comprises three sub-categories. This category addresses how institutions communicate and enact digital pedagogies for training teachers. The first sub-category addresses "*Course structure & design*" (SC25), specifically the importance of different modes of delivery, such as online, hybrid and blended learning. Institutions need to provide guidance on expectations of how these modes of teaching should be implemented (e.g., Galway et al., 2020). This is particularly important for preservice teachers, as they build their understanding of different learning designs and pedagogical approaches. As an example, Şen and Hava (2020) reported

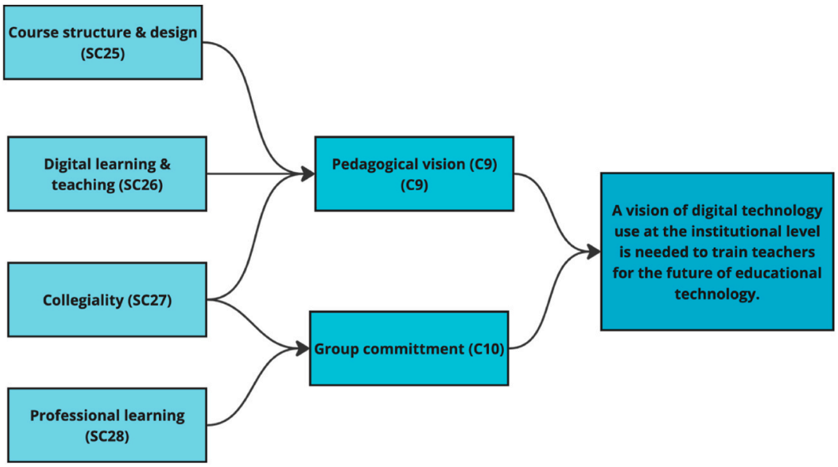

Fig. 8. Categories contributing to synthesis 6.

on the use of a flipped classroom model. Teaching courses need to model desired approaches and learning designs, to give preservice teachers experience in these formats. The value of this was also evidenced in the importance placed on ICT-stand-alone courses, as part of teacher training degree s (e.g. Dewa & Ndlovu, 2022; Şen & Hava, 2020). In Tomczyk, Mascia, and Guillen-Gamez (2023) study this was illustrated through the process of preservice teachers' skill development. Eutsler's (2022) findings also emphasise the benefit of a stand-alone ICT course, expressing the value of preservice teachers being *"familiar with an app before starting on an assignment to prevent any confusion or frustration for the students"*. Teacher training programs need to be structurally designed to afford opportunities for preservice teachers to experience and experiment with digital technologies and different approaches to learning.

Following from this, "*Digital learning & teaching*" (SC26) was the next sub-category. This points to the institutional vision of the teaching methods that are associated with the training of preservice teachers (Eutsler, 2022; Liu et al., 2015). For example, a problem-based approach was frequently identified as a valued pedagogical approach in digital learning (e.g., Lubin & Ge, 2012). Eutsler (2022) designed learning tasks to model the graduate release of responsibility model, which represented different pedagogical approaches: Teacher as Control, Teacher as Facilitator and Problem-based learning. This addressed the need to provide teachers trainers with tangible strategies to develop preservice teachers' digital practice. Students developed more confidence using digital technologies with the teacher-led approaches, in this case iPads, and their understanding of how to teach vocabulary through different apps in the problem-based approach (Eutsler, 2022). In cooperation a range of pedagogical approaches, to familiarise students with digital technologies and provide design opportunities needs to be an underpinning principle of preservice teacher training for future digital practice.

A further dimension of "*Pedagogical vision*" is "*Collegiality*" (SC27). Liu et al. (2015) study demonstrated that preservice teachers experimenting and designing within a project-based paradigm, valued being able to approach mentor teachers for assistance. One student commented that *"I would often wonder about the effectiveness of my instructional strategies, explaining why I often called on my mentor. My mentor also suggested how I could lecture more effectively"* (p. 166). The teaching program increased the frequency of mentor-intern interactions, and especially increased the frequency of interactions concerning technology integration. This is different to collaborating or partnering with mentors. A collegial relationship among preservice teachers and mentors, supports an exploratory and experimental environment which benefits a developing digital practice.

"Collegiality" (SC27) can be fostered at the institutional level in support of the pedagogical vision, but also as part of 'Group commitment' (C10). Group commitment to institutional vision is needed for it to be successfully adopted. However, it is also critical that individuals receive "Professional learning" (SC28) to further support commitment and their ability to enact pedagogical vision. In the Galway et al. (2020) study for instance, a yearlong qualitative study, several participants focused on the ways in which tablets could serve as a mechanism for connecting preservice teachers in communities of practice or professional learning communities. They also argue that professional learning is needed for teacher educators to be in a position to effectively use technology and prepare preservice teachers. Interestingly, in the absence of professional development, learning communities were considered as an alternative in one of the studies (Galway et al., 2020). Therefore, initial and ongoing training and support mechanisms must be designed at the institutional level (see also Liu et al., 2015).

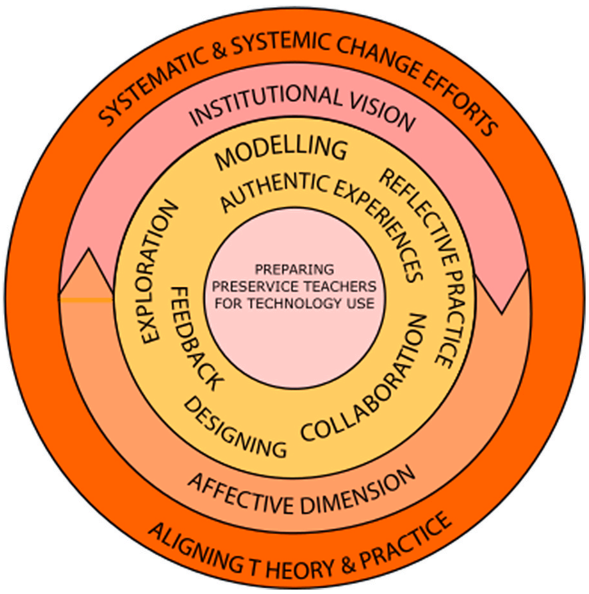

Fig. 9. SQD2 model.

4.2. The overarching SQD2 model

As a final step, the results of the qualitative analysis were presented in a revised SQD model (see Fig. 9). Just like in the original SQD-model (Autors, 2012), the findings were structured into two levels: key themes explicitly related to the preparation of pre-service teachers at the micro level and key themes about conditions necessary to implement strategies, at the meso level. The outermost, macro level, represents the context of preservice teachers' developing digital competence within ongoing change and need to align theory and practice in their training.

However, new categories and most importantly new relationships among them emerged through the current study. For example, "*Exploration*"(C2) came to the forefront of strategies useful to familiarise preservice teachers with the potential of emerging technologies in education. On the meso level, the institutional vision highlights new specific characteristics that sometimes reframe or substitute original leadership, accessibility, staff training and cooperation into a focus on pedagogy, commitment and the affective dimension. All in all, the analyses indicated that the training of preservice teachers for technology integration necessarily requires attention to the relationship between each of the found key categories. Appendix B clearly illustrates that the different categories linked together in a way that made it difficult to address them separately. To illustrate, "*Instructional design activities*" (SC15) has often been associated with "*Authentic experiences*" (SC16). In the discussion section, we elaborate on this perspective and other new emerging themes from the updated SQD2-model. The differences between the original and the SQD2-model are presented in Appendix C and discussed below.

5. Discussion

This systematic review synthesises qualitative evidence on preparing preservice teachers for effective technology integration in education. From this analysis, an updated SQD-model (SQD2, see Fig. 9) has been developed. Below, the findings are discussed into three main sections: 1) the updated strategies identified at the micro level for pre-service teacher preparation; 2) overarching themes essential for the successful implementation of these strategies; and 3) limitations of the study, along with implications for practical application and recommendations for future research directions.

5.1. Updated SQD-strategies to train pre-service teachers

The first synthesised finding, "*familiarisation*", highlights the importance of preparing preservice teachers for the rapidly evolving digital landscape, including emerging technologies and other ways of learning digitally (Emejulu & McGregor, 2019). To equip preservice teachers effectively, modelling new technologies and pedagogical approaches, such as online and blended learning, is essential. While teacher educators remain critical in demonstrating what is possible with emerging technologies (cf., Eutsler, 2022), the updated model additionally emphasises the importance of enabling preservice teachers to actively explore digital technologies, such as simulations (Lee et al., 2022), virtual reality (Orsini-Jones, 2023), and coding (Schina et al., 2021). These technologies underscore the value of hands-on experience, allowing preservice teachers to experiment and build confidence before classroom application (Eutsler, 2022; Butler & Leahy, 2021).

The findings suggest that strategies like modelling, exploration and reflection often complement each other (cf. Şen & Hava, 2020). After becoming familiar with digital technologies, preservice teachers often engaged in reflection on both the potential and limitations of digital technologies in education (e.g., Butler & Leahy, 2021), a theme initially noted in the original Tondeur et al. (2012) study. However, the strategies to reflect in the SQD2-model differ significantly. For example, "*research*" emerged as a new theme, involving preservice teachers in research projects as part of their training (see, e.g., Genç, 2019; Halonen et al., 2023). Recent studies underscore that integrating research into their experience helps bridge the gap between theory and practice (cf., Butler & Leahy, 2021). Another new theme in this respect is the importance of preservice teachers' "*digital identity*" (see Park, 2019). As Engeness (2021) explains, teachers' digital identity is a continuous process of interpreting beliefs, values, and educational experiences in response to contemporary digital contexts. As a consequence, training preservice teachers based on the SQD-strategies could be viewed as actively fostering digital agents who can integrate technology to enhance teaching and learning (cf. Engeness, 2021; Reisoğlu & Çebi, 2020).

A recent development is the use of technology, such as AI, as a scaffold to support preservice teachers in reflecting on their educational practices with technology (Halonen et al., 2023). While AI has only begun to appear in the latest studies, its potential introduces a promising new dimension to teacher training (Hew et al., 2023). To illustrate, Somasundaram et al. (2020) developed an AI-application that assists in setting learning goals and recommending action plans, utilising real-time data student profiles and performance (see also Jin et al., 2023). Although AI collaboration has not yet been incorporated into the design activities identified in this review, collaboration among preservice teachers remains a core strategy in the SQD2-model, especially in designing curriculum materials. Interesting in this respect is the prominent role of the TPACK-framework (Koehler & Mishra, 2009) in guiding these design activities (e.g., Gonen, 2019). To effectively develop pre-service teachers' TPACK, they need opportunities to actively design, collaborate, and reflect on technology use in education (Valtonen et al., 2023). Backfisch et al. (2024) further emphasised that enhancing TPACK depends on preservice teachers' perceived utility of technology, which helps them integrate the different TPACK knowledge bases.

Through collaborative design experiences, preservice teachers emphasised the importance of applying their curriculum materials in authentic settings. In this context, pedagogical reasoning emerged as a new theme (Butler & Leahy, 2021). Encouraging preservice teachers to actively engage in pedagogical reasoning - understanding why, how, and with what outcomes educational technologies are used alongside pedagogical approaches - fosters deeper learning (Forkosh-Baruch et al., 2021). Pedagogical reasoning also connects to preservice teachers' agency in selecting and utilising digital technologies (Tondeur et al., 2018; Cong-Lem, 2021; Juutilianen et al., 2024). This dynamic exchange between agentic actions and pedagogical reasoning is often driven by both internal and external "*feedback"* (Chiu et al., 2024), another effective SDQ2 strategy. Feedback and the reflection on design of the program clearly expand preservice teachers' understanding of teaching with digital technologies (Eutsler, 2022). In this respect, Butler and Leahy (2021) found that preservice teachers value human feedback over machine feedback, highlighting the affective dimension in teacher training. This brings us to the next section.

5.2. New overarching key themes

The updated SQD-model introduces a new set of affective characteristics essential for preparing preservice teachers to integrate technology effectively in educational settings, including the role of emotions (Park, 2019; Şen & Hava, 2020). Ding and Hong (2024) further highlight a significant relationship between emotions and both teacher performance and technology integration. Their findings show that emotions, such as joy, pride, anger, or exhaustion, can substantially influence teachers' ability to integrate technology. This aligns with other studies that point to the importance of factors such as attitudes and beliefs (Diamah et al., 2022; Halonen et al., 2023). Another theme related to the affective dimension is "*Sensitivity to Technology Gaps*". While the original SQD-model focussed on access to devices, the updated literature rather encompasses disparities in digital competence (Nilsson, 2024), intercultural awareness (Shin et al., 2024), or the support for students with learning difficulties (Lee, Davis, & Li, 2022). These findings reflect a shift over the past 10 years in how the field is understanding digital technology integration, that it is not simply about use, but about what it is used for and how it is used.

This brings us to the importance of embedding technology integration as a responsibility shared across the entire teacher training institute (cf. Falloon, 2020; Reisoğlu & Çebi, 2020). As outlined in the original SQD-model, the preparation of preservice teachers to teach with technology should be woven systematically throughout the training program rather than confined to isolated, stand-alone courses. The updated model introduces a focus on a more integrated course structure. With the increasing prevalence of online, hybrid, and blended modes, these delivery structures should now be strategically considered at the institutional level (see Şen & Hava, 2020). Şen and Hava's research for instance indicated that blended learning environments foster greater responsibility among preservice teachers over their learning processes. With respect to the latter, much of the qualitative evidence supports problem-based teaching methods, emphasising independent, critical engagement by pre-service teachers as they explore and implement educational technologies (Eutsler, 2022). Consequently, this insight has led to the development of a new SQD2 theme at the institutional level, which connects the course structure and design with the pedagogical vision (cf. Liu et al., 2015).

The findings also emphasise that professional learning for teacher educators should be addressed institutionally. Interestingly, community of practice was observed across several studies (e.g., Galway et al., 2020; Moran et al., 2023), highlighting efforts to connect teacher educators with collaborative networks, both face-to-face and online, in order to create group commitment (cf. Galway et al., 2020; Moran et al., 2023). The evidence also underscores the role of technology in facilitating these networks to empower teacher educators to use technology effectively. This suggests that a range of training and support mechanisms should be consistently embedded at the institutional level, as supported by Liu et al. (2015) and Moran et al. (2023). Together, these insights indicate that institutionally structured, technology-oriented policies are essential for fostering collegiality and effective strategies among both pre-service teachers and teacher educators.

5.3. Limitations and recommendations

The SQD2-model, while grounded in new qualitative insights, shares a challenge with the original SQD-model (Tondeur et al., 2012) in attempting to distil the complexity of educational technology innovation. Simplifying such a multifaceted process inevitably risks underemphasizing the importance of contextual nuances (Brianza et al., 2024; Wilson et al., 2020). Consequently, the SQD2-model should be seen as a preliminary theoretical construct: a set of "stepping stones" that requires careful consideration of contextual variables. Additionally, there remains much to be explored concerning the differential impact of SQD2-strategies, particularly at the level of individual preservice teachers. Tondeur et al. (2021) previously documented significant variations in preservice teachers' experiences of training strategies, with distinct organisational patterns emerging within SQD-strategies linked to preservice teachers' attitudes towards technology. This variation underscores the necessity of adopting a person-centred approach for developing digital competencies in preservice teachers (cf. Li et al., 2024).

The qualitative evidence presented in this review supports the updated strategies, though it does not establish definitive proof of the effectiveness. Therefore, future research should focus on developing robust instruments to measure the integration of SQD-strategies (cf. Gümüş et al., 2024; Tondeur, van Braak, Siddiq, & Scherer, 2016). Such instruments could enable benchmarking of the support needed by future teachers and facilitate the measurement of its impact on practice. Previous studies indicate that pre-service teachers' perceptions of SQD-strategy implementation are positively associated with self-reported digital competencies, which, in turn, enhance their educational practice (e.g., Tondeur et al., 2016; Hsu & Lin, 2020). In this respect, the SQD2-model can be used to examine the impact on the pre-service teachers' digital competencies. A transparent understanding in the combined effect of these strategies on specific competency frameworks can result in guidelines of educational authorities.

However, the positive impact of the SQD-strategies study should not be perceived simplistically as the 'more the better'. In this respect, the Tondeur et al. (2012) findings highlight potentially important differences in how preservice teachers experience digital competence strategies. More specifically, they found different patterns of associations among SQD-strategies for different profiles of preservice teachers. To illustrate, preservice teachers with more positive attitudes showed a very specific focus on collaboration, while those with lower attitudes had an emphasis on feedback. Therefore, future research should analyse the interrelationships among the SQD2-strategies for the successful development of digital competencies in preservice teachers. Future research should further investigate these differences in preservice teachers' profiles to explore potential pathways for personalised training approaches. Such research would mark a critical first step toward developing an automated, personalised model for fostering digital competence, tailored to the individual needs highlighted by the SQD2-model.

6. Conclusion

In sum, this systematic review provides an updated framework, the SQD2-model, for enhancing preservice teachers' preparedness for technology integration in education. The model synthesises key strategies, emphasising the need for familiarity with emerging digital technologies, such as online and blended learning, artificial intelligence and VR or AR. Reflection and collaborative design are, just like in the original model, core strategies to train preservice teachers for educational technology integration. The inclusion of new dimensions, like digital identity formation, technology as a reflective tool, or affective factors, underscores the complexity of building digital competencies. Furthermore, the study calls for systemic support within teacher training programs to integrate these strategies, moving to a more holistic, program-wide approach, without ignoring the individual differences. Despite its contributions, the SQD2-model remains an initial theoretical projection that must be further validated with contextual insights. Nevertheless, we hope that the new Synthesised Qualitative Data model (SQD2) can inspire policy makers, practitioners, and teacher training institutions all over the world, to better prepare pre-service teachers for technology integration in education.

CRediT authorship contribution statement

Jo Tondeur: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Conceptualization. **Ottavia Trevisan:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Sarah K. Howard:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Conceptualization. **Johan van Braak:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Johan van Braak is an editor of Computers & Education. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compedu.2025.105262.

Data availability

Data will be made available on request.

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