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Research Article

Designing and implementing teacher digital competence programs: An implementation science approach using CFIR 2.0

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ABSTRACT

Teacher digital competence (TDC) is widely recognized as a key enabler of educational digitalization, yet many professional development initiatives do not lead to sustained changes in classroom practice. This study examines the contextual and organizational determinants that should inform the design and implementation of TDC programs in school education from an implementation science (IS) perspective. Drawing on the consolidated framework for implementation research 2.0, a three-round Delphi study was conducted with 23 specialists in educational technology, including teacher educators, school leaders, and system-level advisers. Through qualitative and quantitative analyses, the study developed a model that organizes the main determinants across five domains: intervention characteristics, outer setting, inner setting, characteristics of individuals, and implementation process. The findings suggest that effective TDC programs must extend beyond a narrow focus on individual skills, as their success also depends on leadership, organizational conditions, external support, contextual adaptation, and ongoing evaluation. The model provides a structured basis for designing, implementing, and evaluating programs that are realistic, context-sensitive, and sustainable. Overall, the study demonstrates the value of IS for strengthening teacher professional development in digital education.

Keywords: teacher digital competence, teacher education, implementation science, consolidated framework for implementation research 2.0, professional development

INTRODUCTION

Educational research has generated substantial evidence on effective teaching and learning interventions, yet the translation of this evidence into routine classroom practice remains limited (Rycroft-Smith, 2022). This is especially visible in the field of educational digitalization, where international evidence on system-level

This article derives from the PhD thesis "La competencia digital docente y la transformación de la educación: Evolución y prospectiva [Digital competence for teachers and the transformation of education: Evolution and future prospects]," authored by Mario Hidalgo and supervised by Jesús Valverde-Berrocoso, defended at the University of Extremadura. The thesis is available at http://hdl.handle.net/10662/22438.

impact is still mixed. Recent reports highlight that only certain uses of technology improve specific learning outcomes and warn against “technology-first” approaches that underestimate short- and long-term costs and overlook contextual fit (UNESCO, 2023). Similarly, policy analyses emphasize persistent evaluation gaps, data governance problems and a strong dependence on teacher professional development and institutional leadership for digital technologies to create value across education systems (Escueta et al., 2020; OECD, 2023; Rajasekaran et al., 2024). In this context, the question is not only which technologies are introduced, but how they are implemented and supported in practice.

The digital transformation of education systems hinges on strengthening teachers’ digital competence. Numerous reviews document divergent definitions and metrics, moderate levels of teacher digital competence (TDC), and the persistent difficulty of translating training initiatives into sustained changes in teaching practice (Basilotta-Gómez-Pablos et al., 2022; Berríos-Barra & Calderón-López, 2025; Claro et al., 2024). Considerable effort has been devoted to identifying and describing TDC frameworks (e.g., DigCompEdu), but comparatively less attention has been paid to how professional development initiatives are designed, implemented and sustained in real educational settings. As a result, many TDC programs remain disconnected from school contexts, do not sufficiently address organizational conditions, or fail to achieve long-term changes in classroom practice.

The gap between evidence and routine practice is not unique to education. In healthcare, for example, it has been widely reported that only a fraction of evidence-based practices are adopted in clinical settings, often after considerable delays (Balas & Boren, 2000). In response to this challenge, the field of implementation science (IS) emerged in the early 2000s as the scientific study of methods and strategies that support the systematic uptake of research findings and evidence-based interventions into everyday practice and policy (Bauer et al., 2015; Lyon et al., 2024). IS focuses on understanding and influencing the determinants of adoption, fidelity, penetration, sustainability and cost of interventions, and offers conceptual tools that may be highly relevant for the design of educational innovations, including digital learning initiatives for teachers.

To date, most applications of IS in educational settings have focused on school-based health programs, rather than on transforming teaching and learning practices themselves. Examples include studies on implementing obesity-prevention interventions in schools, on the organizational supports required for teachers to deliver cognitive-behavioral therapy programs, or on strategies to promote healthy-eating policies in school canteens (Eiraldi et al., 2014, 2024; Smith et al., 2022; Wolfenden et al., 2014). In parallel, a distinct body of work has examined education about IS, through systematic reviews, competency analyses and training programs aimed at developing implementation skills among professionals (Brownson et al., 2025; Carlfjord et al., 2017; Davis & D’Lima, 2020; Juckett et al., 2022; Padek et al., 2015; Ullrich et al., 2017). However, there is a notable lack of studies that apply IS frameworks and strategies to pedagogical innovations (e.g., curriculum, subject-specific didactics, and formative assessment) outside the health domain, and virtually no work that uses these approaches to guide TDC programs.

Within IS, a rich range of theories, models and frameworks has been developed to conceptualize and study implementation processes (Fontaine et al., 2025; Nilsen, 2015). Among them, the consolidated framework for implementation research (CFIR 2.0) is particularly relevant for education. CFIR, as shown in **Figure 1**, organizes the determinants of implementation into five domains: intervention characteristics, outer setting, inner setting, characteristics of individuals and implementation process (Reardon et al., 2025). The updated CFIR 2.0 has been refined based on extensive user experience over more than 15 years and applied across multiple sectors (Kirk et al., 2016; Means et al., 2020; Mullin et al., 2024; Safaeinili et al., 2019; Schmitt et al., 2025). By structuring attention to multilevel contextual factors, such as leadership, organizational climate, resource availability and practitioners’ beliefs, CFIR is well suited to educational contexts, where the success of TDC programs depends on system-level policies, school conditions and teachers’ motivations.

CFIR 2.0 provides practical guidance to diagnose barriers and facilitators across domains, to select aligned implementation strategies (e.g., facilitation, audit and feedback, and leadership engagement) and to evaluate results using implementation outcomes such as adoption, fidelity, sustainability and cost (Damschroder et al., 2022; Kirk et al., 2016; Means et al., 2020; Reardon et al., 2025; Safaeinili et al., 2019; Schmitt et al., 2025). Importantly, CFIR does not replace pedagogical or curricular frameworks for TDC. Rather, it is intended to complement competence frameworks such as DigCompEdu and didactic decisions (e.g., situated learning,

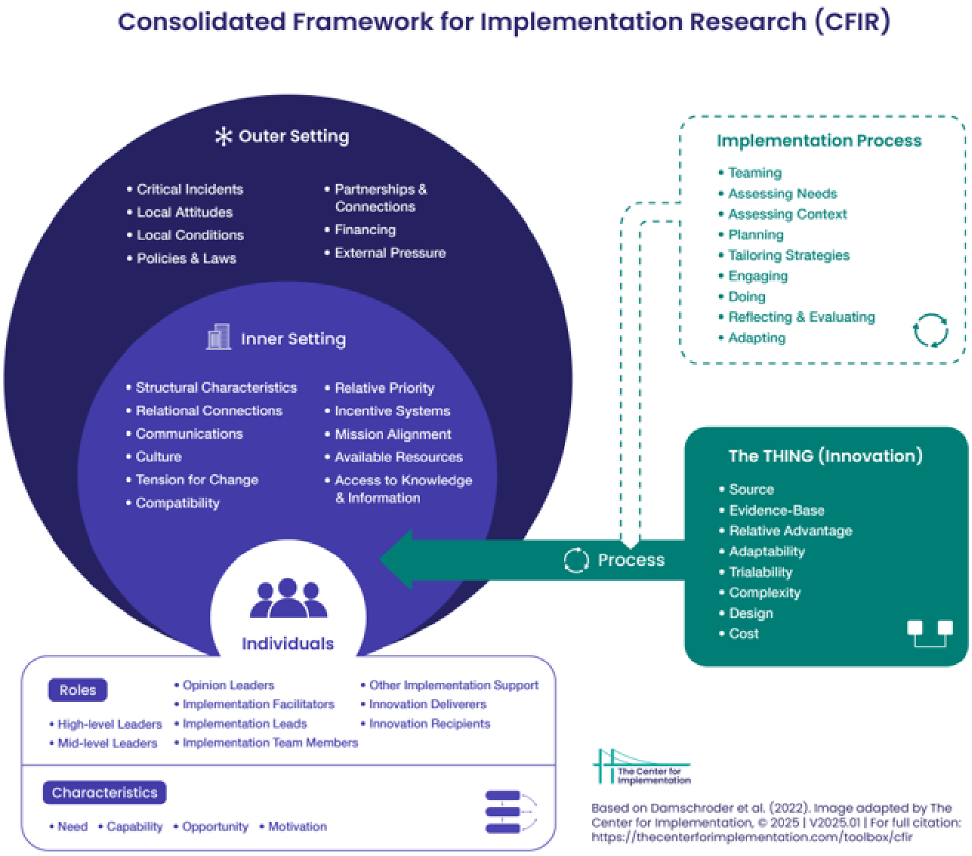

Figure 1. CFIR 2.0 (image adapted by the Center for Implementation. Version: V2025.01. https://thecenterforimplementation.com/toolbox/cfir)

micro-credentials, and communities of practice). In the context of teacher education, CFIR can help structure the assessment of contextual determinants, guide the adaptation of TDC programs to specific schools and systems, and support the selection of strategies that make professional development initiatives more realistic and sustainable.

Designing TDC programs according to the principles of IS and under the CFIR 2.0 framework is therefore a methodological opportunity for teacher education. It allows a more rigorous diagnosis of why training does not consistently translate into sustained digital practices, supports the alignment of program design with schools' actual barriers and resources, and enables evaluation in terms of implementation outcomes that matter in specific educational contexts (Hidalgo, 2024).

Against this backdrop, the present study explores the use of CFIR 2.0 as a framework to guide the design and implementation of TDC programs in compulsory education. The overall objective is to assess the suitability and usefulness of CFIR for TDC training from the perspective of key stakeholders involved in educational digitalization. Specifically, the study aims to:

(1) assess the perceived relevance of each CFIR domain and construct for the design and implementation of TDC programs;

(2) estimate the clarity and operability of these constructs for education managers, training teams and schools; and

(3) analyze whether CFIR adequately covers the determinants that stakeholders consider critical for successful TDC implementation.

METHODS

This study used a Delphi design to reach consensus among specialists on the determinants that influence the implementation of TDC training programs in compulsory education. The Delphi method was selected because it supports a systematic, transparent process for integrating multiple expert perspectives around a shared conceptual framework, in this case, the CFIR 2.0. The study combined qualitative and quantitative elements across three iterative rounds, allowing participants to refine and prioritize implementation determinants over time.

Participants and Recruitment

Participants were selected through purposive sampling based on three criteria:

(1) professional track record,

(2) degree of specialization in educational technology, and

(3) diversity of institutional contexts.

The aim was to assemble a panel capable of providing informed, complementary views on the design and implementation of TDC programs.

An initial pool of 42 candidates was invited. Of these, 23 completed all three rounds of the Delphi process. Panel members came from different educational levels and from both public and private sectors. To capture perspectives across system levels and roles, participants were grouped into four profiles:

(a) Experts: education professionals with deep knowledge of educational technology, experience in teacher training for digital education, and recognized scientific or technical contributions.

(b) Specialists: education professionals with a high degree of applied specialization in educational technology and extensive experience in designing, implementing or evaluating TDC initiatives.

(c) Facilitators: education professionals with experience advising and training in-service teachers in the adoption of educational technologies at school or program level.

(d) Users: teachers who use educational technology in their daily practice and provide a classroom-based perspective on needs, constraints and opportunities.

This configuration was intended to ensure a cross-cutting view of TDC implementation, spanning policy, program design, school-level facilitation and classroom practice.

Data Collection Procedures

The Delphi exercise unfolded in three consecutive rounds conducted online.

- Open exploration of determinants (round 1). An online questionnaire with five open-ended questions was administered, each aligned with one of the five CFIR 2.0 domains (intervention, outer setting, inner setting, characteristics of individuals and implementation process). Participants were asked to describe, in their own words, the main barriers, facilitators and contextual conditions that affect the implementation of TDC training programs in their context. This round generated a rich corpus of narratives and examples.
- Refinement of statements (round 2). Based on the round 1 corpus, the research team developed a closed questionnaire that translated the qualitative material into a set of declarative statements linked to CFIR domains and constructs. Participants were asked to indicate their level of agreement with each statement on a Likert-type scale, with the goal of transforming open-text responses into quantifiable, prioritizable indicators and assessing the degree of convergence among panelists. During analysis of round 2 responses, a high level of agreement was observed for many statements. To avoid redundancy and to maximize discrimination among priorities, the research team decided to move directly to a final ranking round rather than repeating another rating round. The Delphi protocol was initially designed with three iterations. However, the high thematic convergence observed after the open round led the research team to omit the planned intermediate rating round and proceed directly to the final prioritization stage. Participants were therefore presented with a consolidated set of determinants derived from the qualitative analysis and asked to rank their relative importance. This adaptive decision was intended to avoid redundancy and reduce respondent burden.
- Prioritization of determinants (round 3). In the third round, participants were presented with a consolidated list of determinants derived from the previous phases and were asked to rank their relative importance for the successful implementation of TDC programs. This forced-ranking exercise

required participants to make explicit trade-offs among items, generating data suitable for examining both central tendencies and patterns of consensus within and across profiles.

Throughout the process, panelists remained anonymous to one another. After each round, they received controlled, aggregate feedback on the emerging results (e.g., summary of statements and their relative positioning) and de-identified comments, allowing them to reflect on the group's views before responding to subsequent rounds.

Data Analysis

The textual corpus from round 1 was analyzed with IRaMuTeQ using the Reinert method of descending hierarchical classification. This procedure segments the corpus into elementary context units and groups words into semantic classes based on co-occurrence and chi-square associations. In addition, correspondence factor analyses were conducted to explore the relational structure among classes and to visualize discursive polarities in the panel. Interpretation combined three elements:

(1) identification of the highest-weight keywords in each class,

(2) examination of representative text segments, and

(3) analysis of the distribution of classes across participant profiles.

This triangulation of quantitative outputs with close qualitative reading allowed the research team to refine and label semantic classes as preliminary sets of implementation determinants linked to CFIR domains and constructs.

Responses from round 2 were used to assess the degree of agreement on the statements derived from round 1. Descriptive statistics were calculated to examine distributions and tendencies for each item. These results informed the selection and refinement of the items that were carried forward to the final ranking round, prioritizing those that were consistently recognized as relevant across profiles.

In round 3, the ranking data were analyzed in two main ways. First, means and standard deviations of ranks were computed to assess the centrality and dispersion of priorities for each determinant. Second, Kendall's coefficient of concordance (W) was used to estimate the level of agreement among participants regarding the ordering of items. Interpretation followed conventional thresholds (0-0.20 slight; 0.20-0.40 fair; 0.40-0.60 moderate; 0.60-0.80 substantial; ≥ 0.80 almost perfect). Analyses were conducted for the full panel and, where informative, by participant profile to explore possible differences between experts, specialists, facilitators and users. All statistical analyses were performed using R, and text analyses were carried out with IRaMuTeQ.

Ethical Considerations and Responsible Use of Generative AI

All participants received detailed information about the study, signed informed consent and took part under conditions of confidentiality. No personally identifiable information was disclosed at any stage of the Delphi process. The study protocol was approved by the Comisión de Bioética y Bioseguridad de la Universidad de Extremadura (Spain) on 17 July 2024 (approval code 148//2024).

A large language model (LLM) was used only as a support tool during the research process. Specifically, it assisted the authors in:

(1) suggesting initial thematic labels for classes and partitions already generated by IRaMuTeQ,

(2) drafting brief preliminary summaries of characteristic segments to inform team discussions, and

(3) harmonizing terminology during the writing phase.

The LLM did not generate data, run statistical analyses or modify classifications; all numerical results (frequencies, Chi-square statistics, dendrograms, correspondence analyses, and rank-based statistics) were produced exclusively by IRaMuTeQ and/or R. Human oversight was maintained throughout, with all suggestions checked against the source texts and original outputs. No sensitive or personally identifiable data were entered into the LLM. Its use does not confer authorship; the authors retain full responsibility for the study design, analysis and interpretation.

Table 1. Summary of Delphi study results across the five CFIR domains

CFIR domains	Main semantic classes	Key findings
1. Intervention characteristics	Governance and design (25.5%) Contextualization and needs (24.8%) Perceived usefulness and fit (20.5%) Methods and improvement (15.5%) Resources and costs (13.7%)	Effectiveness depends on the balance between economic feasibility, clear governance, pedagogical relevance, and contextual adaptation.
2. Outer setting	Needs assessment and external supports (41.7%) Structural support conditions (38.8%) School culture and innovation (19.4%)	Implementation is shaped by infrastructure and resources; it is strengthened by an innovation-oriented culture and external supports tailored to identified needs.
3. Inner setting	Participatory culture and enabling environment (23.1%) Normative-organizational framework (22.3%) Results-oriented planning (21.5%) Access, support, and time (16.9%) Leadership and faculty commitment (16.2%)	Organizational change is articulated in five stages: collaborative culture, operational support, normative framework, evaluable planning, and shared leadership.
4. Characteristics of individuals	Exploration and experimentation with ICT (34.1%) Measurement and progress in TDC (22.7%) Engagement and motivation (22.7%) Interest and variability of participation (20.5%)	The decisive personal attributes are intrinsic motivation, willingness to experiment, perceived progress, and a diversity of interests that require flexibility.
5. Implementation process	Monitoring and adaptation (19.0%) Realism and professional judgment (18.1%) Clear and coherent planning (17.2%) Learning from practice (17.2%) Leadership and institutional anchoring (15.5%) Formative assessment (12.9%)	Implementation unfolds as a cycle: realism and situated practice, institutional leadership, continuous evaluation, flexible monitoring, strategic planning, and transferable good practices.

RESULTS

Overview of the Implementation Model

The three-round Delphi process yielded a CFIR-based model of determinants that influenced the design and implementation of TDC programs in compulsory education. Analyses of the round 1 corpus produced several coherent semantic classes that were mapped onto CFIR 2.0 domains and constructs. These classes captured panelists' descriptions of barriers, facilitators and contextual conditions surrounding TDC initiatives at system, school and classroom levels.

The resulting categories were translated into statements for round 2 and subsequently refined into a set of determinants for the final ranking in round 3. Across domains, participants consistently emphasized that the success of TDC programs depends not only on the quality of training content, but also on how initiatives are aligned with system-level expectations, supported within schools and experienced by teachers as realistic and meaningful in their local contexts.

The findings are presented in line with the five domains of the CFIR 2.0. The Delphi analysis made it possible to identify consistent semantic classes that, taken together, constitute an implementation model for TDC programs in educational settings. The full report with a detailed analysis of the study is available at https://doi.org/10.5281/zenodo.17116848. **Table 1** shows the summary of Delphi study results across the five CFIR domains.

Table 2 presents the highest-priority determinant within each CFIR domain or ranking block, together with the corresponding descriptive statistics and W.

Differences between professional profiles were examined through profile-specific Kendall's W coefficients across the six ranking blocks. Kendall's W for the full panel ranged from .09 to .43 across the six ranking blocks. Concordance was moderate for individual characteristics (W = .43), fair for the two intervention blocks and the outer setting (W = .23-.36), and slight for the inner setting and implementation process (W = .09-.10). Five of the six coefficients were statistically significant; only the implementation-process block did not reach significance. Profile-based analyses showed different patterns of concordance. Users/facilitators reached their highest agreement in the first intervention block (W = .44). Experts showed moderate concordance in

Table 2. Highest-priority determinants and agreement in the final Delphi round

CFIR domain	Highest-priority determinant	Mean rank (SD)	Ranked first	W
Intervention characteristics (I)	Teachers' expectations	2.0 (1.8)	65.2%	.36
Intervention characteristics (II)	Training adapted to the educational context	2.0 (1.4)	43.5%	.23
Outer setting	Comprehensive assessment of teachers' needs	1.8 (1.5)	73.9%	.28
Inner setting	Leadership teams as promoters of change	3.5 (2.4)	30.4%	.10
Characteristics of individuals	Teachers' attitudes	2.3 (1.6)	-	.43
Implementation process	Implementation consistent with the plan	1.8 (0.8)	43.5%	.09

Note. Lower mean ranks indicate higher priority; Kendall's W was statistically significant for all blocks except the implementation-process block; & SD: Standard deviation

the first intervention block and individual characteristics (W = .48 in both cases), whereas specialists obtained the highest profile-specific coefficient for individual characteristics (W = .59). Given the small subgroup sizes, these results are interpreted as exploratory patterns rather than stable or generalizable differences between professional profiles.

The final model was constructed through a sequential process. First, the open responses were analyzed separately for each CFIR domain using descending hierarchical classification and correspondence analysis. Second, the central ideas represented in the lexical classes and characteristic text segments were converted into concise declarative statements, with redundant propositions merged and compound statements separated. Third, these statements were organized by CFIR domain and submitted to the final forced-ranking round. The model therefore integrates the deductive structure of CFIR 2.0, the inductively identified lexical classes, and the relative priorities assigned by the panel.

In what follows, we present the results by CFIR domain: intervention characteristics, outer setting, inner setting, characteristics of individuals and implementation process. Within each domain, we summarize the most salient determinants and their relative importance as indicated by the panel.

Intervention Characteristics

Determinants associated with the intervention domain captured how TDC programs are designed, perceived and adapted. Participants highlighted several key features that shape teachers' willingness and ability to engage with training and to transfer learning into practice.

First, panelists stressed the importance of perceived relevance and coherence. TDC programs were seen as more implementable when their objectives, content and assessment criteria are clearly connected to teachers' everyday teaching tasks, school priorities and existing competence frameworks. Vague or overly generic initiatives were described as "noise", competing with other demands without offering tangible support for classroom practice. Second, complexity and workload emerged as central considerations. Programs perceived as overly complex, fragmented or time-consuming were described as unlikely to be completed or translated into sustained changes. Participants advocated for modular, phased designs that allow for progressive engagement, with a realistic balance between training requirements and teachers' existing workload. Third, panelists emphasized the value of adaptability and customization. While some degree of standardization was considered necessary (e.g., alignment with national frameworks such as DigCompEdu), participants argued that TDC interventions should provide room for local adaptation to school characteristics, student profiles and existing digital infrastructures. Flexible pathways, choice of activities and differentiated support were seen as important facilitators of implementation. Overall, determinants in this domain point to the need for TDC programs that are clearly framed, context-sensitive and manageable in scope, so that teachers perceive them as practically useful rather than as an additional bureaucratic requirement.

Outer Setting

Determinants in the outer setting domain referred to system-level factors and external supports that shape how TDC programs are initiated and sustained. Participants underscored the role of policy coherence and continuity. TDC initiatives were perceived as more likely to succeed when embedded in medium to long-term digital education strategies, with consistent messages from educational authorities, stable funding and clear expectations about digital competence for teachers and schools. Conversely, short-term projects, frequent policy changes and fragmented programs were seen as undermining implementation. A second cluster of determinants concerned external support and inter-institutional collaboration. Panelists highlighted the importance of advisory services, regional or municipal support centers and networks that provide expertise, coaching and resources to schools. External facilitators were viewed as key actors in helping schools interpret policy, adapt TDC programs to their context and sustain momentum over time. Finally, participants pointed to alignment with broader digital and curricular agendas. TDC programs were described as more implementable when they connect with existing initiatives (e.g., digital infrastructure plans, curriculum reforms, and innovation projects) rather than being experienced as isolated or redundant efforts. Such alignment was seen as crucial for avoiding "initiative fatigue" and leveraging synergies across policies. Taken together, these determinants suggest that TDC programs cannot be fully understood or implemented at school level alone; they are shaped by the stability, clarity and supportiveness of the wider educational ecosystem.

Inner Setting

The inner setting domain captured determinants related to organizational context at the school and provider level, which panelists consistently described as decisive for implementation. Determinants in this domain suggest that TDC implementation depends on schools' capacity to integrate digital competence development into their organizational routines, priorities and support structures, rather than treating it as an isolated training event.

Across profiles, there was strong agreement on the importance of leadership and vision. School leaders who articulate a clear digital vision, allocate time and resources to TDC, and model engagement with digital tools were seen as crucial facilitators. In contrast, an absence of leadership commitment was frequently mentioned as a barrier, even when high-quality training was available. A second group of determinants concerned organizational culture and climate. Participants highlighted that TDC programs are more likely to take root in schools where collaboration, peer learning and experimentation are encouraged, and where teachers feel psychologically safe to try new practices and share difficulties. In more individualistic or compliance-driven cultures, TDC initiatives were often reduced to formal accreditation rather than genuine pedagogical change. Third, panelists underscored the relevance of structural conditions such as time, infrastructure and technical support. Without protected time for training and collaborative work, access to adequate devices and connectivity, and reliable technical assistance, even well-designed TDC programs were seen as difficult to implement. These structural determinants were described as «non-negotiable» prerequisites rather than optional add-ons.

Characteristics of Individuals

The characteristics of individuals domain focused on how teachers and other professionals involved in TDC programs perceive and engage with digital competence development. Overall, determinants in this domain highlight the need for TDC programs that recognize and address the diversity of teachers' starting points, beliefs and motivations, and that position digital competence as integral to teacher professionalism.

Panelists identified beliefs about the value of digital technologies as a key determinant. Teachers who see digital tools as meaningful for student learning and inclusion were described as more likely to invest time and effort in TDC programs, whereas those who view technology mainly as a source of disruption or additional workload tended to engage superficially or resist participation. Another central determinant was self-efficacy and confidence. Participants noted that low levels of perceived digital competence can be a barrier if programs are not designed to provide supportive entry points and visible early successes. Conversely, training that scaffolds progression and acknowledges prior experience was seen as helpful in building confidence and agency. A third group of determinants related to motivation and professional identity. TDC programs were described as more effective when they tap into teachers' intrinsic motivations (e.g., improving learning, supporting diverse students, and innovating in pedagogy) and when digital competence is framed as a core component of professional responsibility rather than a technical add-on.

Implementation Process

Finally, the implementation process domain captured how TDC programs are introduced, coordinated and iteratively adapted. Determinants in this domain suggest that TDC programs benefit from being treated as evolving processes rather than fixed products, with deliberate strategies to engage stakeholders, provide support and adapt over time.

Participants emphasized the importance of co-design and participation in planning TDC initiatives. Involving teachers, school leaders and other stakeholders in defining goals, selecting content and deciding modalities was described as increasing ownership and relevance, and as helping to anticipate potential barriers. A second set of determinants involved ongoing facilitation and support. TDC programs were seen as more likely to be implemented when they include sustained accompaniment (e.g., coaching, mentoring, and peer observation), rather than relying solely on isolated workshops. The presence of internal or external facilitators who can bridge policy, program design and classroom practice was repeatedly mentioned as a facilitator. Third, panelists pointed to the need for monitoring, feedback and adaptation. Implementation was described as a dynamic process in which data on participation, teacher experiences and early outcomes should be used to adjust program content, pacing and support mechanisms. When such feedback loops were absent, TDC initiatives tended to lose momentum or remain misaligned with school realities.

Summary of the CFIR-Based TDC Implementation Model

Across domains, the Delphi results converge on a CFIR-based model in which TDC implementation is shaped by interactions between the design characteristics of programs, the wider policy and support environment, the organizational conditions of schools, the beliefs and capacities of individual teachers and the way implementation is orchestrated over time.

The model underscores that TDC programs are most likely to translate into sustainable digital learning practices when they:

(1) are coherent, manageable and adaptable to local contexts;

(2) are embedded in stable, supportive outer-setting conditions;

(3) are integrated into schools' leadership, culture and structures;

(4) consider teachers' beliefs, motivations and self-efficacy; and

(5) are supported through participatory, well-facilitated implementation processes.

This model provides a structured map of implementation determinants that can inform the design, monitoring and refinement of TDC initiatives in compulsory education, and serves as the basis for the discussion and implications developed in the next section.

DISCUSSION

This study used the CFIR 2.0 framework to identify and prioritize determinants that influence the implementation of TDC programs in compulsory education. Through a three-round Delphi process with specialists in educational technology, we generated a CFIR-based model that articulates how intervention characteristics, outer and inner setting factors, characteristics of individuals and implementation processes interact to shape TDC initiatives (Damschroder et al., 2022). In this section, we discuss the contributions of this model to research on digital learning in teacher education, derive implications for the design and leadership of TDC programs, and outline limitations and directions for future work.

Contributions to Research on Digital Learning in Teacher Education

The first contribution of this study is to bridge the gap between TDC frameworks and the conditions under which TDC programs can be effectively implemented. Much of the existing literature has focused on defining TDC domains, indicators and levels, or on documenting teachers' self-perceived digital competence and use of digital tools (Basilotta-Gómez-Pablos et al., 2022; Domínguez-González et al., 2025; Redecker, 2017; Revuelta-Domínguez et al., 2022; Smestad et al., 2023). In contrast, our findings emphasize that having a detailed competence framework is necessary but not sufficient. Implementation depends on a wider configuration of determinants that include policy coherence, school leadership, organizational culture, structural resources, and teachers' beliefs and motivations.

By structuring these determinants through CFIR 2.0, the study offers a multi-level perspective that complements outcome-oriented or tool-focused approaches to digital learning in teacher education. Recent analyses of the digital transformation of school education underscore that system-level strategies often underestimate the organizational and cultural work required in schools and over-rely on technology provision alone (Boeskens & Meyer, 2025; Forsström et al., 2025). Our model illustrates how TDC programs are situated at the intersection of macro-level strategies (e.g., digital education policies and funding schemes), meso-level conditions (e.g., school vision, collaboration cultures, and time allocation) and micro-level factors (e.g., self-efficacy, perceived relevance, and professional identity). This perspective aligns with calls to move beyond individual teacher variables and to consider the organizational and systemic dimensions of digital transformation in education (McCarthy et al., 2023).

A second contribution lies in the adaptation and operationalization of CFIR 2.0 within an educational, non-health domain. IS has been developed largely in healthcare as "the scientific study of methods to promote the systematic uptake of research findings into routine practice" (Eccles & Mittman, 2006, p. 1). Within this field, the CFIR 2.0 is one of the most widely used determinant frameworks to assess contextual factors affecting implementation (Damschroder et al., 2009, 2022). Previous work in schools has applied IS mainly to health-related interventions (e.g., prevention and well-being programs) or has focused on training professionals in IS itself.

This study extends the scope of CFIR by using it to interrogate the implementation of pedagogical innovations (in this case, TDC programs), where the primary outcomes are changes in teaching and learning practices rather than health indicators. Our Delphi-based operationalization shows that CFIR domains and constructs can be meaningfully reinterpreted in educational terms and rendered usable by stakeholders who do not have prior IS training. The updated CFIR 2.0 explicitly aims to center recipients of innovations and to improve usability across sectors (Damschroder et al., 2022), and our findings suggest that these goals are attainable in the context of teacher education and digital learning.

This adaptation is not a mere transfer of a framework from one field to another. Rather, the results suggest a productive dialogue between IS and digital learning in teacher education. CFIR helps make explicit the assumptions and contextual dependencies of TDC programs, while the specificities of educational contexts (e.g., curriculum pressures, assessment regimes, school governance, and teacher autonomy) challenge and enrich how CFIR constructs are understood and prioritized. The resulting model thus contributes to an emerging strand of research that explores how implementation frameworks can be used to design and evaluate complex educational interventions beyond the health domain (Bauer & Kirchner, 2020; Bauer et al., 2015).

Implications for the Design and Leadership of TDC Programs

The CFIR-based model derived from this study has several implications for teacher educators, school leaders and policy makers involved in TDC initiatives. These implications are particularly relevant for teacher education programs responsible for preparing both preservice and in-service teachers for technology-rich learning environments.

At the level of program design (intervention characteristics), our findings underline the importance of ensuring that TDC programs are coherent, manageable and adaptable. Designers should explicitly connect learning objectives, activities and assessments to teachers' everyday practices and to school priorities, avoiding generic or purely technocentric approaches that previous reviews have identified as a limitation of some TDC initiatives (Domínguez-González et al., 2025; Revuelta-Domínguez et al., 2022). Programs should be structured in modular, phased formats that acknowledge teachers' workload and allow for gradual progression. Incorporating flexible pathways, practical tasks linked to real classrooms and differentiated support can enhance perceived relevance and feasibility.

From an outer setting perspective, TDC programs should be embedded in stable and coherent policy frameworks. Comparative studies on digitalization policies highlight the importance of long-term strategies, consistent messages and alignment between infrastructure, curriculum and professional development (Boeskens & Meyer, 2025; European Commission, 2023; OECD, 2023). Educational authorities can support implementation by articulating such strategies, providing predictable funding, and connecting TDC initiatives with broader agendas such as competence-based curricula, inclusion policies or AI strategies. Building and sustaining advisory networks and support centers that offer expertise, coaching and resources to schools can also serve as a critical external facilitator, particularly for institutions with limited internal capacity.

Within the inner setting, the model emphasizes the centrality of school leadership and organizational culture, echoing findings from research on digital transformation in schools (McCarthy et al., 2023). School leaders play a pivotal role in setting a digital vision, legitimizing TDC as a strategic priority, allocating time and resources, and modelling engagement with digital tools. TDC programs are more likely to lead to sustained change when they are integrated into school development plans, supported by structures for collaboration (e.g., professional learning communities, co-teaching, and peer observation) and anchored in a culture that values experimentation and shared learning. Without such conditions, TDC often remains an individual endeavor, disconnected from collective instructional improvement.

Regarding characteristics of individuals, the model suggests that TDC initiatives should explicitly address teachers' beliefs, motivations and self-efficacy, which have been repeatedly identified as critical for technology integration (Basilotta-Gómez-Pablos et al., 2022; Smestad et al., 2023). Program designers and facilitators need to recognize that teachers enter TDC programs with varied experiences and attitudes towards digital technologies. Providing supportive entry points, acknowledging existing expertise, and framing digital competence as a means to enhance student learning and inclusion, not merely as a technical requirement, can foster more meaningful engagement. Activities that allow teachers to experience early successes in their own classrooms and to share these experiences with colleagues may help build confidence and ownership.

Finally, the implementation process dimension highlights the need to treat TDC programs as iterative, participatory processes rather than one-off training events, in line with broader IS recommendations (Bauer & Kirchner, 2020; Damschroder et al., 2022) involving teachers and school leaders in co-designing goals, content and modalities can increase relevance and buy-in. Implementation should be accompanied by ongoing facilitation, whether through internal coordinators, external advisors or hybrid roles, that bridges policy and practice, providing support as teachers experiment with new digital practices. Establishing mechanisms for monitoring and feedback (e.g., regular reflection meetings, surveys, and classroom observations) can inform iterative adaptations and help maintain momentum over time.

Taken together, these implications suggest that stakeholders should use the CFIR-based model not only as a diagnostic tool but also as a design and planning framework. For example, before launching a TDC initiative, a system or school could use the model to:

(1) assess strengths and gaps across domains;

(2) select implementation strategies aligned with key barriers and facilitators; and

(3) plan for the evaluation of implementation outcomes such as adoption, fidelity and sustainability (Damschroder et al., 2022).

Limitations and Future Research

The study has several limitations that should be considered when interpreting the findings and that point to avenues for future research. First, the Delphi panel, although composed of experienced professionals in educational technology and teacher training, was relatively small and context-specific. The determinants identified and prioritized reflect the perspectives of these particular stakeholders and educational systems. The findings should be interpreted in light of the relatively small and context-specific panel, the exploratory nature of the profile-based analyses, and the absence of validation through observed program implementation. The model is therefore proposed as an expert-informed heuristic framework that requires further testing across educational contexts. Future studies could replicate or extend the Delphi with larger, more diverse panels, including representatives from additional countries, school types or roles (e.g., students, parents, and non-teaching staff), to test the robustness and transferability of the model. Second, this research focused on expert judgement rather than on observing TDC implementation in situ. While experts' insights are valuable for conceptualizing determinants and building consensus around priorities, the actual effects of these determinants on implementation outcomes remain to be empirically tested. Subsequent research could use the CFIR-based model to guide case studies, longitudinal designs or mixed-methods evaluations of specific TDC programs, examining how variations in determinants relate to adoption, quality of implementation and sustainability of digital practices, as IS studies have done in other sectors (Bauer &

Kirchner, 2020; Damschroder et al., 2009). Third, while the study demonstrates the potential of CFIR 2.0 in educational contexts, it does not exhaust the possibilities for integrating IS frameworks and tools into digital learning research. Other implementation models (e.g., those focusing on specific strategies, readiness, or stages of implementation) could be combined with CFIR to develop more comprehensive approaches (Bauer & Kirchner, 2020). Similarly, further methodological work is needed to adapt IS measurement instruments, such as scales for organizational readiness or implementation climate, to teacher education and digital learning settings (Damschroder et al., 2022).

Despite these limitations, the study provides a grounded, stakeholder-informed starting point for using CFIR 2.0 to design, implement and evaluate TDC programs. By making implementation determinants explicit and highlighting their interconnections, the model invites researchers and practitioners to move beyond content-focused or technology-driven perspectives and to consider the broader systemic and organizational conditions required for sustainable digital learning in teacher education.

CONCLUSIONS

By adapting CFIR 2.0 to the context of digital learning in teacher education, the study contributes a structured, multi-level perspective that helps make explicit the contextual assumptions underlying TDC programs. The model can support teacher educators, school leaders and policy makers in

(1) diagnosing barriers and facilitators across system, school and classroom levels;

(2) designing TDC programs that are coherent, manageable and adaptable to local conditions; and

(3) planning implementation strategies and evaluation efforts that focus not only on competence acquisition, but also on adoption, fidelity and sustainability.

Used in this way, CFIR becomes a practical tool for moving from "technology-first" initiatives to context-sensitive professional development paths that are more likely to result in meaningful digital learning practices.

For research, the study offers a stakeholder-informed starting point for integrating IS frameworks into the study of teacher education and digitalization. The CFIR-based model provides a set of theoretically grounded, empirically prioritized determinants that can be used to guide future case studies, longitudinal designs and mixed-methods evaluations of specific TDC programs. Further work is needed to test the model in diverse contexts, to refine measurement instruments for key constructs and to explore how CFIR can be combined with other implementation and pedagogical frameworks to support complex educational change.

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AI statement: A large language model was used only as a support tool to suggest provisional thematic labels for classes and partitions already generated by IRaMuTeQ, draft preliminary summaries of characteristic segments for team discussion, and harmonize terminology during writing. It was not used to generate data, conduct statistical analyses, modify classifications, or make interpretive decisions. All suggestions were checked against the source texts and original analytical outputs. No sensitive or personally identifiable data were entered into the tool. The authors retain full responsibility for the study design, analysis, interpretation, and final text.

Declaration of interest: The authors declared no competing interest.

Data availability: Aggregated item-level ratings for rounds 2-3, Kendall's W by subgroup and overall, the round-1 coding framework, decision rules, and study metadata are openly available at https://doi.org/10.5281/zenodo.17116848. Individual-level or potentially identifying qualitative data are not shared; access may be granted on reasonable request for non-commercial academic use.

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