Developing Teachers' Digital Competence through Expansive Learning: A Study of Teacher–Researcher Collaborative Teaching Research

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Abstract: As education rapidly digitalizes and technologies like generative AI continue to evolve, strengthening teachers' digital competence has become more crucial than ever. However, many existing training programs are highly structured and pay limited attention to the diverse needs teachers encounter in their own classrooms. This study explores how expansive learning supports the development of teachers' digital competence (TDC) and transformative agency. Based on a case of collaborative curriculum design between teachers and researchers, the research analyzes how teachers identify and resolve systemic tensions in practice. Using the DigCompEdu framework and agency analysis, the findings reveal a four-phase developmental trajectory-Questioning and Analysis, Modeling and Testing, Implementation and Reflection, and Consolidation and Standardization-through which teachers evolve from passive users of digital tools to active pedagogical innovators. The study highlights the importance of collaborative, reflective, and practice-driven professional learning in advancing digital competence.

Keywords: Teacher Professional Development, Digital Competence, Expansive Learning, Collaborative Design

1. Introduction

With the rapid advancement of emerging technologies such as generative AI, teaching and learning are undergoing profound change (Wohlfart & Wagner, 2023). Strengthening teachers' digital competence has thus become urgent. In many national and regional frameworks, the role of teachers is shifting from simply using tools to transforming pedagogy through technology (Redecker, 2017). Yet, despite relevant policies, the ability to effectively integrate digital tools is still not widely recognized as core professional competence (Instefjord & Munthe, 2016). Existing training programs often follow fixed pathways and overlook individual and disciplinary needs (Gisbert Cervera & Lázaro Cantabrana, 2015; Papanikolaou et al., 2017; ElSayary, 2023). Addressing this gap, this study uses expansive learning theory to examine how teachers, in collaboration with researchers, identify systemic tensions, co-construct solutions, and enact classroom transformation, and how such processes activate transformative agency and foster digital competence.

2. Literature Review

2.1 Teachers Digital Competence

Digital competence is widely recognized as a core 21st-century skill for citizens in the digital era. In the field of teacher education, a range of conceptual models has been proposed to articulate its complexity. The widely adopted TPACK model highlights the multifaceted nature of digital integration by emphasizing the interrelationship between technological, pedagogical,

and content knowledge (Mishra & Koehler, 2006). Complementing this, the PEAT model maps the developmental trajectory of digital literacy along two dimensions, offering a dynamic view of competence growth (McDonagh et al., 2021). As digital technologies continue to evolve, the scope of teachers' digital competence has expanded beyond basic operational skills to encompass ethical awareness, digital safety, and creative thinking. This shift reflects a broader understanding of digital competence as a composite capacity to integrate technologies effectively in multi learning environments and to enhance instructional quality (Falloon, 2020).

Viewing digital competence solely as an individual attribute risks overlooking the broader organizational and contextual dynamics that shape its development. Rather than isolating digital competence at the level of single actors, it is more productively understood as a collective and institutional responsibility, influenced by structural and cultural conditions within the school system (Pettersson, 2018). This perspective has prompted a rethinking of professional development models. Increasingly, scholars advocate for collaborative and co-constructed approaches, where educators and researchers work together to define problems, co-design strategies, and engage in reflective inquiry. Such models facilitate knowledge co-creation and support context-sensitive pedagogical innovation (Shun et al., 2021).

Because digital competence is context-specific, its development requires not only technical skills but also the ability to align digital tools with pedagogical goals. This shifts teachers from passive implementers to informed decision-makers navigating complex contexts, embodying transformative agency—the capacity to break from established practices and initiate change (Brevik et al., 2019). Activating such agency is key to advancing digital competence and fostering sustainable professional identity growth.

2.2 Expansive Learning in Teacher Professional Development

Expansive Learning Theory, rooted in Cultural-Historical Activity Theory (CHAT), provides a framework for understanding how teachers identify and resolve systemic contradictions to achieve professional transformation (Engeström, 2001; Engeström & Sannino, 2010). It shifts the focus from learning as mere internalization to a process where individuals or collectives create new practices through concrete activities. Engeström's (2001) seven-stage cycle illustrates how such practices are transformed under the drive of contradictions.

Figure 1 includes the following iterative stages: Questioning current practices; Analyzing the root causes of contradictions; Constructing a new model; Examining the new model; Implementing the new practice; Reflecting on and evaluating the process; Consolidating and disseminating new practices. The process is not linear but recursive, emphasizing the generative and sustained nature of practice transformation.

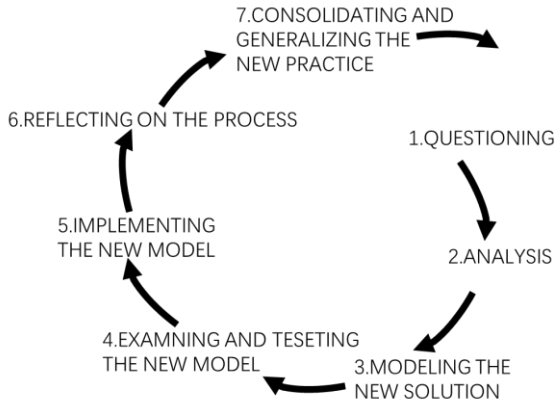

Figure 1. Expansive learning cycle

This theory has been widely applied in fields such as education and organizational change, particularly in contexts like vocational training, healthcare education, and teacher development, to understand how collectives reconstruct existing practices in response to changing external conditions (Engeström, 2010). In teacher education, expansive learning is

seen as a crucial pathway for enhancing teachers' professional agency and fostering collective transformation. Existing studies primarily focus on teachers' collaborative construction of practices in curriculum reform, co-designed pedagogy, and technology-supported teaching (Sannino, 2016; Pareto et al., 2022; Augustsson et al., 2021). Although expansive learning has been widely applied in teacher education research, its role in supporting the development of teachers' digital competence remains underexplored and warrants further investigation.

This study adopts expansive learning theory as its analytical lens to reveal how teachers navigate the transformation from digital awareness to pedagogical innovation within cross-boundary collaborations, complex tasks, and practice-driven communities. The research focuses on the following two questions:

RQ1: How does teachers' digital competence change during expansive learning, and what drives this transformation?

RQ2: How does teachers' transformative agency emerge and develop through collaboration around digital competence?

3. Research Design

3.1 The systemic context and participants

This study was conducted by a collaborative team composed of members from School C and University H (Figure 2). The participants included one vice principal from School C (C1), two teachers (C2, a primary science teacher, and C3, a STEM teacher teaching both primary and secondary school), one professor from University H (H1), and two graduate students (H2 and H3). Each member contributed based on their area of expertise, forming a cross-institutional co-design team. The object of this collaborative activity was a STEM curriculum project titled "Designing a Digitally Micro-Weather Station."

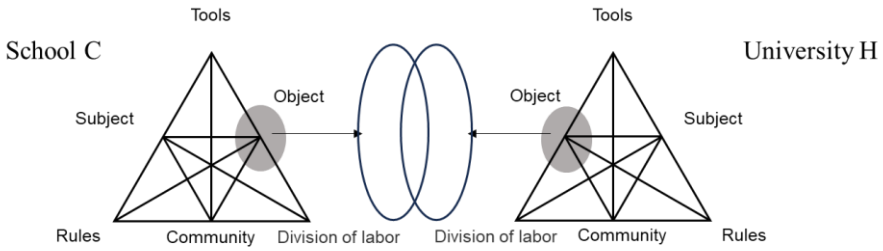

Figure 2. The activity system for collaborative team

The project fostered students' interdisciplinary thinking and problem-solving by integrating meteorology, engineering education, and ICT. Resources included lesson plans, slides, videos, simulations, open-source hardware, and interactive whiteboards. School C and University H formed a collaborative community, guided by curriculum standards, objectives, and assessment criteria. Roles were clearly divided: graduate students (H2, H3) drafted plans and developed content; teachers (C2, C3) taught; the vice principal (C1) coordinated; and the professor (H1) offered guidance. Pre- and post-lesson research discussions refined content and strategies.

3.2 Data Collection

The collaborative course was implemented from March to June 2024, with six lessons in total. These were co-designed and iteratively refined by the team. To comprehensively capture the dynamic changes during this collaboration, two main types of data were collected including audio and video recordings of teaching discussions among teachers and researchers before and after each lesson; as well as documents generated during curriculum design, including lesson plans, instructional slides, draft scripts.

3.3 Data Analysis

Guided by the theoretical framework of expansive learning, the researchers independently reviewed the full set of transcripts, observation notes, and design documents to trace the developmental trajectory of teachers' digital competence and the emergence of their transformative agency throughout the collaborative process. The aim was to identify key patterns of change and turning points in practice that reflected shifts in professional understanding and pedagogical innovation.

Multiple team discussions resolved coding disagreements. Using Engeström's (2001) seven-stage expansive learning cycle as a guide, observed actions were mapped to theory, then iteratively coded from transcripts, notes, and design documents. Overlapping actions were merged into four empirically grounded phases: (a) questioning and analysis—identifying systemic contradictions and reflecting on limits of current digital teaching; (b) modeling and testing—co-designing and trialing digitally integrated instructional approaches; (c) implementation and reflection—applying and refining solutions in classrooms; and (d) consolidation and standardization—stabilizing, sharing, and internalizing effective practices. This theory-informed yet empirically refined framework captures both the logic of expansive learning and the observed developmental trajectory, structuring the findings to show teachers' digital competence growth and transformative agency in collaboration.

To examine the development of teachers' digital competence and the emergence of their transformative agency during the collaborative curriculum design and implementation process, this study adopted a dual analytical framework. The European Framework for the Digital Competence of Educators (DigCompEdu) (Redecker, 2017) was used to analyze the trajectory of digital competence development. DigCompEdu outlines six core areas: professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence. Each area includes specific competences that describe how educators use digital technologies to enhance teaching and learning. In this study, these areas were used to code and interpret changes in teachers' awareness, knowledge, and skills observed in teaching discussions, document writing, and classroom practice.

To analyze transformative agency, the study adopted the coding framework developed by Virkkunen (2006) and Haapasaari et al. (2016), which defines it as the capacity of individuals or groups to break away from established practices and proactively reconstruct their activities. Teachers' reflective dialogue was coded entirely according to their six expressions of agency: (a) resisting, (b) criticizing, (c) explicating, (d) envisioning, (e) committing to actions, and (f) taking actions. This framework was applied directly to capture cognitive shifts and emerging agency in response to systemic tensions.

By combining the DigCompEdu framework with the lens of transformative agency, this study mapped teachers' professional growth across multiple dimensions. This dual approach revealed how reflective critique, collective negotiation, and practical experimentation contributed to both the development of digital competence and the activation of transformative agency during the expansive learning process.

By incorporating the Expansive Learning Cycle, the study further analyzed which stage of the cycle the teachers were situated in throughout the process. This helped to reveal the interactive relationship between the development of digital competence and the emergence of transformative agency. Through this triangulated analytical approach, the study aimed to comprehensively uncover the mechanisms by which teachers move from "using technology" to "reconstructing pedagogy" in participatory practice.

4. Results

This section presents the research findings based on the four phases. Each phase is analyzed from two dimensions: (a) the developmental trajectory of teachers' digital competence (based on the DigCompEdu framework), and (b) the generation and evolution of teachers' transformative agency. This structure reveals the dynamic interplay and trajectory between

teachers' professional growth and the enhancement of their agency throughout the co-construction of the curriculum.

4.1 Questioning and Analysis Phase

Digital Competence Development

Early in curriculum preparation, teachers struggled to implement a STEM project unit using Arduino boards and sensors. Despite prior experience with multimedia tools, they were unprepared for tasks involving hardware operations and programming, revealing gaps in digital competence, especially in "Teaching and Learning" and "Digital Resources."

The lack of confidence was evident as teachers struggled to design lessons that combined subject knowledge, digital tools, and hands-on creation. As C3 noted, *"This type of class is completely new to me. I have never had experience teaching a course that integrates hardware components and digital tools like this before."* Teachers also showed hesitancy in managing technological complexity in the classroom. C2 commented, *"I think it's very difficult to ask students to both build and design the device in class. It's too much for them to process at once."* These statements reflected the perceived gap between what the curriculum expected and what the teachers felt equipped to deliver.

In addition, during interdisciplinary collaboration and co-planning sessions, teachers found it challenging to engage in professional discourse that relied heavily on technical vocabulary. This hindered their active involvement and weakened their sense of agency. C1 explained, *"When the engineers talk about components and logic, I often don't know how to respond, so I just stay quiet."* The inability to participate fully in these discussions revealed a lack of readiness not just in technical skills but in collaborative digital engagement.

At this stage, the most prominent feature of teachers' digital competence development was not technical mastery but rather the emergence of awareness — an acknowledgment of the challenges ahead and an increased sensitivity to what digital teaching truly demands. This awareness became the starting point for future learning and adaptation through sustained practice.

Transformative Agency —— Resisting and Criticizing

In response to the challenges of project-based STEM teaching, teachers began to express an emerging form of transformative agency. Rather than blindly executing instructional plans, they started to question and evaluate the pedagogical logic and practical feasibility of the tasks assigned to them. This marked an important shift: from passive recipients of externally designed curricula to active participants in reshaping them.

One key expression of this agency was resistance — teachers openly voiced doubts about the ambitious nature of the project tasks. C2 remarked, *"It's very difficult to ask students to both design and build the device within class time."* Similarly, C1 reflected, *"We don't even have enough time to prepare properly ourselves. Expecting students to manage everything in one class is too much."* These remarks reflect concern not with rejecting innovation, but with ensuring that instructional design is responsive to classroom realities. The resistance was rooted in pedagogical care: teachers were advocating for more realistic goals that matched their students' cognitive and time capacities.

Beyond task design, teachers also began to critique their roles within the interdisciplinary collaboration process. They noticed a structural imbalance in which technical voices often dominated, while pedagogical insights were sidelined. As C3 observed, *"Sometimes I just listen because I'm not sure whether my ideas align with what the researchers are saying."* C1 similarly noted, *"It feels like I'm expected to follow the structure that's already decided. There's not much space to bring in my own perspectives."* These comments reveal not only communication difficulties but also a sense of marginalization within the collaborative framework.

By both questioning unrealistic goals and expressing concerns about unequal collaboration, teachers showed a deeper kind of professional initiative. Teachers were no longer confined to the role of executors but began positioning themselves as evaluators and reformers of both the instructional content and the institutional process. While still tentative,

this marked a meaningful step toward empowered professional identity in digitally mediated, interdisciplinary teaching environments.

4.2 Modeling and Testing Phase

Digital Competence Development

In the modeling and testing phase, teachers showed marked improvement in digital competence, taking greater initiative in shaping instructional strategies. Growth was evident in "Teaching and Learning," "Digital Resources," and "Facilitating Learners' Digital Competence."

One of the key shifts was their growing ability to anticipate students' learning difficulties and respond through supportive instructional design. C3, for example, proposed: *"We could create small instruction cards for each device, including pin details and wiring guides."* This suggestion reflected a shift from problem-solving in the moment to proactive planning. Rather than seeing technical complexity as a disruption, teachers began integrating it as a component of structured learning. The use of customized aids, simplified wiring diagrams, and visual flowcharts indicated their increasing mastery in aligning technical content with pedagogical scaffolding.

Moreover, teachers became more strategic in adapting the sequencing of classroom activities to support student engagement and pacing. As they better understood both the affordances of digital tools and the cognitive demands placed on learners, they adjusted their instructional flow accordingly. This reflected a deeper competence in harmonizing technology with teaching rhythms and demonstrated their growing confidence in orchestrating complex classroom environments.

Overall, digital competence at this phase was no longer merely about technical handling; it evolved into a student-centered, anticipatory planning approach where digital tools were embedded meaningfully within pedagogical structures.

Transformative Agency —— Envisioning

In contrast to the earlier phases dominated by doubt and resistance, this stage was marked by the emergence of *envisioning*—a form of transformative agency in which teachers began to imagine and design improved instructional pathways. This capacity was not simply about reacting to problems, but about constructing alternatives based on classroom experience and pedagogical reflection.

Teachers demonstrated this agency through concrete proposals for redesign. In one planning session, both C2 and C3 suggested reordering the lesson flow: *"I think we can change the order of the activities to better match students' response rhythms."* This proposal signaled more than a surface-level rearrangement; it reflected a shift in how teachers conceptualized instruction—as a flexible, adaptive process shaped by students' needs rather than a rigid plan to be followed.

Such envisioning also revealed teachers' increasing ownership over the instructional process. They were no longer acting as implementers of an externally imposed curriculum but were becoming co-designers, capable of restructuring both content and delivery. Their confidence to intervene was supported by their expanding understanding of interdisciplinary collaboration. As they became more familiar with the technical side of the project, they were better able to articulate how design elements could support learning outcomes.

Furthermore, their ideas began to reflect a hybrid logic—combining learning theory, student psychology, and practical constraints of classroom time and materials. C1, for instance, discussed balancing task complexity with emotional engagement: *"Students feel excited when things light up or move, but if we do too much too fast, they get anxious. Maybe we need to slow down some parts."* This sensitivity to emotional pacing demonstrated not only pedagogical awareness but also a deepening of design-oriented thinking.

In sum, the envisioning observed at this stage indicated a growing pedagogical imagination and professional maturity. Teachers were not merely adapting—they were beginning to lead change by proactively shaping the structure and flow of instruction in digitally enriched environments.

4.3 Implementation and Reflection Phase

Digital Competence Development

During implementation, teachers brought the co-designed curriculum into classrooms and faced challenges such as student errors, hardware malfunctions, time pressure, and fluctuating engagement. These required them to apply digital competence more adaptively, particularly in "Teaching and Learning," "Assessment," and "Professional Engagement."

Faced with students frequently miswiring components, teachers learned to slow down and scaffold learning with more care. C2 shared, *"Students kept wiring things incorrectly, so I slowed down and started explaining and demonstrating step by step."* C1 similarly noted, *"After two or three groups failed to make their work, I realized I had to break the explanation into simpler parts."* These instructional adjustments reflected not only improved classroom management, but also a more effective use of digital tools in response to learner needs.

In addition, teachers became more engaged in post-lesson reflections, drawing upon data provided by researchers—such as student behavior logs and video excerpts—to analyze and revise their instructional strategies. This marked a shift toward more evidence-informed practice. They began asking: Where did confusion arise? How did pacing affect focus? What kinds of support worked best? Such questions signaled a growing comfort with professional inquiry and iterative improvement.

Finally, several teachers began to reflect on how their instructional design choices influenced student engagement. Some noticed that when they gave students more freedom, motivation increased—even if the results were imperfect. This recognition marked a subtle but significant evolution in digital competence: a blending of technical proficiency with pedagogical intuition, aimed at fostering deeper student involvement.

Transformative Agency —— Explicating

In this phase, teachers' transformative agency evolved from adaptation to explanation. Through reflective analysis, they began explicating—making visible the contradictions in their teaching and tracing the sources of misalignment between curriculum design, classroom flow, and student engagement. This shift toward explanation marked a higher-order form of agency rooted in reasoning, not just intuition.

Teachers became more articulate about why certain instructional structures were misfiring. C3 questioned, *"Can we let students design their own process for the operation part? Even if it gets messy, they'll be more engaged."* C2 supported this idea: *"When I tried to lead every step, students just waited passively. But when I gave them some room, they started trying things on their own."* These observations moved beyond surface behavior to pedagogical logic: teachers realized that too much control could suppress inquiry and engagement.

They also turned their attention inward, analyzing personal teaching habits. C1 admitted, *"I've realized I tend to over-structure everything. I plan for every minute, but these tasks need more room to breathe."* Teachers began to reflect on whether traditional classroom norms—tight timing, precision, control—were suitable for open-ended, hands-on STEM tasks. They no longer focused solely on whether lessons succeeded, but on the deeper reasons behind classroom tensions.

While full-scale redesigns were not yet common, the move toward explicating marked an essential cognitive shift. Teachers were engaging in structured reflection, questioning default patterns, and beginning to formulate alternatives based on student thinking, emotional pacing, and collaborative dynamics. It was a crucial step toward transformative professionalism.

4.4 Consolidation and Standardization Phase

Digital Competence Development

As the project neared completion, teachers' digital competence stabilized and extended beyond the classroom. Digital practice became part of institutional routines, with leaders converting their experiences into school-based resources, training materials, and shared

frameworks for peer learning—reflecting advanced competence in “Professional Engagement” and “Digital Resources.”

C1 suggested, *“We could compile all of this into a training kit so other teachers can use it too.”* C3 similarly proposed, *“What if we turn our lesson plans into a guidebook, with examples and student work samples?”* These comments indicated that teachers were no longer simply users of digital tools—they were becoming contributors to a professional knowledge base, with an eye toward scalability and sustainability.

Moreover, digital competence had become part of the school’s internal professional culture. Teachers were now confident in designing digital tasks, troubleshooting in real-time, and adapting resources for varied instructional needs. This institutionalization of competence represented a critical transformation: digital skills were no longer personal or experimental—they were shared, repeatable, and capable of being transferred across classrooms and departments.

Transformative Agency —— Committing to actions

In this final phase, teachers’ transformative agency matured into committing to actions—a proactive stance where teachers not only embraced digital innovation but also assumed responsibility for spreading and sustaining it. They moved from adapting to innovation to driving it, actively shaping peer learning, departmental planning, and school-wide strategies.

C2 expressed, *“Next semester, I want to lead a training for other science teachers—this design has really changed my view of tech-based instruction.”* C1 echoed this commitment: *“I’m already drafting a template other teachers can use. It’s a way to keep the work going after the project ends.”* These statements illustrate a key evolution: teachers no longer positioned themselves as recipients of innovation but as professional actors capable of influencing broader systems.

This agency was not limited to individual enthusiasm. It manifested in organized efforts to share, standardize, and institutionalize practices. Teachers began meeting regularly to draft internal documents, revise workflows, and coordinate across subjects. They discussed how to embed successful approaches into school policy and even proposed rotating leadership structures to sustain innovation cycles. Through these actions, they demonstrated agency not just in response to their own classrooms, but in shaping collective capacity and institutional culture.

By this stage, teacher agency had extended from reflection and critique to systemic participation. The commitment to act showed that innovation had become part of their identity—not as a temporary project, but as a professional responsibility integrated into their long-term teaching practice.

5. Discussion and Conclusion

This study explored how teachers’ digital competence was developed through a process of expansive learning that unfolded across four interconnected phases (Figure 3), i.e., Questioning and Analysis, Modeling and Testing, Implementation and Reflection, and Consolidation and Standardization. Within this process, teachers engaged in sustained professional learning by confronting and resolving contradictions within the activity system, such as contradictions and tensions between digital tools and instructional objectives or between institutional rules and classroom realities (Chen et al., 2024; Engeström, 2020).

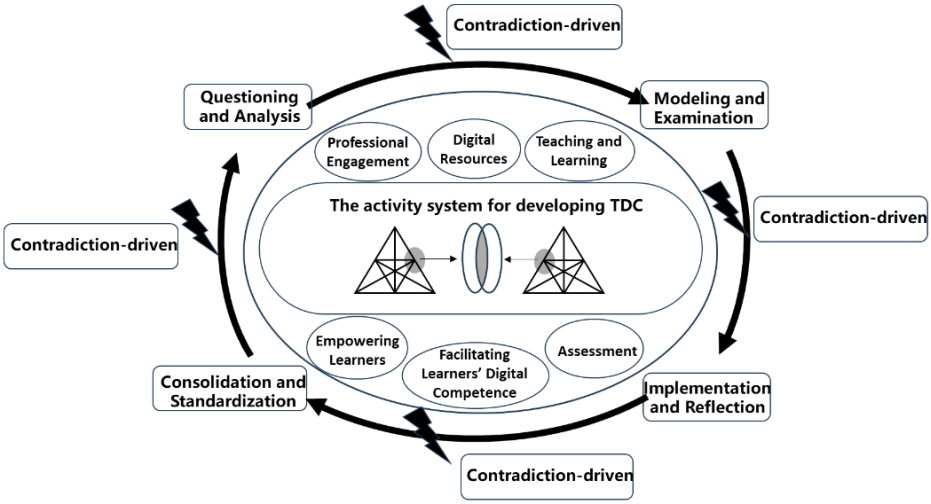

Figure 3. *A Model of Expansive Learning for Teachers' Digital Competence Development*

As they progressed through collaborative lesson planning, experimentation, and reflection, teachers came to see how digital tools could support pedagogy by aligning with student needs, enabling real-time feedback, and fostering learner agency. This shift marked a move from basic adaptation to deep pedagogical integration. Transformative agency developed alongside this change: teachers questioned ineffective routines, proposed alternatives, and increasingly committed to new practices through peer training, resource codification, and participation in organizational decision making (Wei & Sannino, 2024). This commitment signaled a shift from individual trial to institutional ownership and leadership. The process also underscored the collective, dialogical nature of teacher learning, as mixed communities of researchers and practitioners integrated local insights with theoretical guidance, creating a shared culture of digital innovation. This aligns with Bakhtin's (1982) concept of multivoicedness, where diverse dialogue fosters critical thinking and creative problem solving. Digital competence here emerged not as a fixed skill set, but as a capacity evolving through iterative cycles of identifying problems, designing and testing solutions, and refining practices based on student responses (Englund & Price, 2018). Theory and practice reinforced each other: theoretical insights informed action, while teaching experience refined conceptual understanding.

In sum, this study contributes to the theoretical articulation and empirical demonstration of how expansive learning fosters sustainable and context-sensitive development of teachers' digital competence. It shows how digital competence and transformative agency co-evolve, and why professional learning must be collaborative, practice-based, and theory-informed to respond to the challenges of digitalization.

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