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Editorial

Editorial: Empowering Teacher Professionalization with Digital Competencies

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1. Introduction

As digital technologies continue to reshape education, equipping teachers with digital competencies has become a pressing need in both policy and research across Europe and worldwide. Teachers are widely recognized as change agents in shaping and implementing meaningful digital learning experiences in schools (Foster, 2023). Accordingly, international organizations such as the OECD (2023) have emphasized the urgent need to prepare teachers for teaching in technology-supported and digital contexts, and thus, to systematically support their ongoing professional development in this domain.

International empirical findings have highlighted that, while teachers across different countries acknowledge the relevance of their digital competencies, they often report insufficient preparation during their initial teacher education (see Eickelmann et al., 2019; Fraillon et al., 2020; OECD, 2023). In response, various European countries have established initiatives and funding programs aimed at strengthening the digital competencies of teachers—often through stronger connections between research, practice, and policy. In recent years, teacher education institutions across Europe have taken important steps toward integrating digital education into initial teacher education and professional development (see Norhagen et al., 2024; Richter et al., 2024; Rubach & Backfisch, 2024; Tomczyk & Fedeli, 2022). In many countries, the promotion of teachers' digital competencies has now been formally regulated and is increasingly anchored in teacher education curricula as an explicit educational goal (OECD, 2023). Correspondingly, research has increasingly addressed this development by examining topics such as teacher professional development programs for in-service teachers, (extracurricular) learning opportunities in teacher education, and the role of teacher educators and their education (Arstorp et al., 2024; Lazarides et al., 2024; Norhagen et al., 2024). Building on these foundations, research continues to emphasize the importance of understanding how learning opportunities have to be designed in order to influence the development of digital competencies of pre-service and in-service teachers (Norhagen et al., 2024; Rubach & Backfisch, 2024). Research based on (quasi)-experimental interventions suggests, for example, that different goals—whether emphasizing pedagogical integration, technical functionality, or hands-on application—affect the distinct aspects of teachers' digital competence needed for their profession (Ning et al., 2022). Despite the vivid empirical research carried out in this field, it is still an unresolved question whether, how and under which conditions pre-service and in-service teachers benefit from professional development formats that aim to increase their digital competencies.

To address this gap, the present Special Issue provides a platform for experts from both teacher education and teacher professional development who have examined the quality

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and design of technology-supported learning environments and their impact on pre-service and in-service teachers' digital competencies. In line with research on high-quality teaching, the studies in this Special Issue emphasize both the process dimension, i.e., how instruction is designed, and the product dimension—what is to be learned. By drawing on these findings, we are now in a position to not only conclude that certain formats successfully foster teachers' digital competencies, but also to understand how such learning formats need to be designed in order to be effective. The work presented in this Special Issue informs education research about central preconditions to foster teachers' digital competencies systematically, and also provides knowledge for educational practice about the design principles of teacher education as well as teacher professional development programs.

2. Perspectives on Teacher Professionalism in the Digital Era

The professionalism of educators in the digital era refers to the idea that teachers possess the necessary digital competencies and that they align their behavior with these competencies to effectively navigate and shape digital teaching and learning environments (Krumsvik, 2011; Redecker, 2017). Multiple theories and frameworks provide important insights into competencies that provide grounding for teachers' professional behavior in the digital era (see for an overview Rubach & Lazarides, 2023). In line with these frameworks, we differentiate between basic and professional digital competencies whereby basic digital competencies are the mandatory grounding to develop the full potential of professional digital competence (Rubach, 2024). This developmental perspective suggests that both basic and professional digital competencies form digital competence (see Hämäläinen et al., 2021; Law et al., 2018; Rubach, 2024).

Based on the definition of the general professional competence of teachers by Blömeke and Kaiser (2017), we posit that, transferred to the digital context, the basic digital competence of teachers consists of the knowledge, motivational beliefs and skills and practices required when using technology to analyze and select digital data and information, to communicate and collaborate online and participate in the digital world, to create and share digital content, to perform tasks and solve problems in digital environments or by using technology, to be responsible with privacy, to protect health and the environment and to reflect on and analyze the ongoing digital changes and essential phenomena of technology (Calvani et al., 2008; Ferrari, 2013; Ilomäki et al., 2016). Professional digital competence then builds on these basic digital competencies and consists of the knowledge, motivational beliefs and skills required when using technology "with good pedagogic-didactic judgement and [. . .] awareness of its implications for learning strategies and the digital Bildung of pupils and students" (Krumsvik, 2011, p. 45). Taking these definitions as the orientation for educating (future) teachers, it becomes clear that the development of digital competencies is a complex and multi-layered endeavor. First, it is essential to address both basic and professional digital competencies in teacher education and training. Second, multiple educational goals are subsumed under this broader objective—namely the promotion of knowledge, motivational beliefs, such as competence-related beliefs, value beliefs, or attitudes, and situation-specific skills (see Lachner et al., 2021; Max et al., 2022; Rubach et al., 2019; Sáez-López et al., 2023). Third, the development of these competencies cannot be limited to a single stage of the professional career path for teachers. Instead, the development of teachers' digital competencies must be conceptualized as a successive, longitudinal and cumulative process that spans initial teacher training, early-career induction, and ongoing professional development, particularly as new technologies and opportunities for the use of technology in educational settings are constantly emerging. To understand how digital competence can be developed in this longitudinal and cumulative process, it is essential to examine the quality of learning environments.

3. Perspectives on the Quality of Learning Environments to Support Teacher Professionalism in the Digital Era

To effectively support teachers in their professional development—particularly in this digital era—we can draw on insights from instructional quality research. This field emphasizes that high-quality teaching and learning environments are defined by the integration of both a process and product perspective: how (good) learning happens (i.e., the process), and what is (intended to be) learned (i.e., the product) (Reusser & Pauli, 2021; Praetorius & Gräsel, 2021). Understanding how such environments are designed is essential for enabling effective professionalization.

Didactic perspectives on teaching contribute to this understanding by offering conceptual tools with which to analyze and design instruction in a way that systematically aligns learning processes with the intended outcomes. The central assumptions are that effective teaching requires the careful coordination of multiple interrelated components: the content to be taught, the methods of instruction, the learners' prerequisites, and the sociocultural and organizational conditions in which learning takes place (e.g., Heimann et al., 1979; Helmke, 2022). These elements must be considered collectively, as the focus is not merely on the effectiveness of a single method (process) but on how various elements can be integrated to support the intended learning outcomes (product).

In the context of digitalization, two central goals emerge for both pre-service and in-service teachers: teaching with technology and teaching about technology (Eickelmann et al., 2019; Krumsvik, 2011; Rubach, 2024; Redecker, 2017; OECD, 2023). Addressing these goals requires a process-oriented comprehension of how to support the development of digital competencies through carefully constructed instructional settings in teacher education. This, in turn, raises the question of how instructional processes must be structured—a question that integrates didactic elements with a consideration of both content-generic and subject-specific teaching strategies (see Charalambous & Praetorius, 2020). Whereas content-generic standards can be applied to support competence development among all contents and subjects, content-specific standards help identify the design of learning processes necessary for learners to develop an understanding of specific content (Reusser & Pauli, 2021). Charalambous and Praetorius (2020) emphasized the importance of establishing a shared understanding of instructionally meaningful and high-quality learning processes. We adopt this perspective in the present Special Issue and apply it to teacher education—specifically in preparing teachers to use technology effectively and to nurture the digital competencies required for this task.

This reflection is grounded in the MAIN-TEACH model (which is multi-layered and integrated, conceptualizing the quality of teaching, Charalambous & Praetorius, 2020). This model is informed by the German models of opportunities and uses of instruction (see Helmke, 2022). The model emphasizes instructional processes as contributing to student learning only when learning opportunities are not only provided for but also embraced by learners, resulting in meaningful learning activities. The MAIN-TEACH model distinguishes three levels of instructional quality. At the core lies the principle of differentiation and adaptation to learners' needs, which influences all strategies of instructional quality in the second and third layer. The second layer comprises stand-alone quality dimensions such as classroom and time management, socio-emotional support, and support for active engagement. The third layer focuses on instructional quality dimensions that are intertwined and directly relevant for learning, including four dimensions: "supporting practicing, cognitive activation, formative assessment, and selecting and addressing the content and subject-specific methods" (Charalambous & Praetorius, 2020, p. 5). The MAIN-TEACH model can also serve as a conceptual lens through which to examine how teacher education and teacher professional development programs should be designed to foster

digital competencies. It highlights the need to address both generic and content-specific dimensions of teaching when preparing pre-service teachers and in-service teachers to operate within digitalized learning environments. Simultaneously, the integration of generic- and content-specific dimensions of teaching requires ongoing reflection from a subject-specific perspective on the following lines of inquiry: to what extent are these dimensions sufficient, how differentiated are they, and where might they need to be expanded (see Praetorius & Gräsel, 2021)? For this purpose, established frameworks such as the SQD model (Synthesis of Qualitative Evidence on the Development of Digital Competence) offer valuable guidance for teacher education and technology use. The SQD model by Tondeur et al. (2012, 2025) outlines teaching principles that can be meaningfully aligned with the third level of the MAIN-TEACH model, particularly in guiding the establishment of learning opportunities in teacher education to support pre-service teachers' digital competencies. The SQD outlines six key principles to guide the preparation of pre-service teachers for developing digital competence: having role models, being in authentic environments, training on instructional design, being in collaborative settings, receiving feedback and reflecting on experiences. In this Special Issue, we adopt both generic and content-specific perspectives on instructional quality—focusing on the processes through which learning is facilitated and the intended outcomes—to explore fundamental lines of inquiry investigating how instructional quality contributes to the professional development of pre-service and in-service teachers in the digital era.

4. Studies of the Special Issue

This Special Issue focuses on the effectiveness of instructional characteristics and strategies in supporting the professional development of both pre-service and in-service teachers in the context of digital transformation. Five contributions in this Special Issue examine how digital professionalization unfolds in *pre-service teacher education*, with a focus on the development of motivational beliefs and attitudes, knowledge, and skills, as well as ICT use. These studies investigate a range of learning environments, from curricular classes and extracurricular online courses to school-based internships. Through the perspective of research on instructional quality and the MAIN-TEACH model, the scholars included in this Special Issue analyze key characteristics of these learning environments, for example, what is taught (content), how learning is being facilitated (instructional strategies), and what the outcome of learning processes is.

Runge, *Hebibi*, and *Lazarides* investigated the role of content in fostering pre-service teachers' digital competence, specifically by examining opportunities for engaging with artificial intelligence (AI) in teacher education. Using cross-sectional data from 143 pre-service teachers at multiple German universities, the authors indicated that students who participated in courses addressing AI reported stronger AI-related TPCK beliefs (**T**echnological **P**edagogical **C**ontent **K**nowledge), perceived AI tools as easier to use and more useful, and demonstrated greater intentions to use AI in future classrooms. Furthermore, higher levels of perceived usefulness were associated with both a greater intention to use AI and more frequent use of AI.

Another key focus is the development of pre-service teachers' diagnostic skills for identifying students' cognitive engagement when using technology in the classroom, and exploring how teacher education can effectively foster such skills. These diagnostic competencies are crucial for meaningful technology integration, as they enable teachers to assess the learning potential and impact of digital tools on students' cognitive processes. *Roeben*, *Vejvoda*, *Murböck*, *Fischer*, *Schultz-Pernice*, *Lohr*, *Stadler*, *Sailer* and *Heitzmann* examine the use of a simulation-based learning environment which provides an authentic yet simplified setting in which pre-service teachers can practice and develop their diagnostic skills. Draw-

ing on data from 213 pre-service teachers at a German university, the authors validated the simulation tool in a pre–post design. Their findings indicate that the simulation effectively elucidated pre-service teachers' difficulties in accurately determining students' cognitive engagement during ICT-supported instruction.

Hirsch and *Rubach* investigate the instructional strategies implemented in teacher education courses and their longitudinal effects on changes in pre-service teachers' professional digital competence beliefs—specifically, their beliefs regarding technological pedagogical knowledge (TPK) and technological pedagogical content knowledge (TPCK). The authors focus on the instructional strategies outlined in the SQD model (Tondeur et al., 2012), such as providing role models, enabling interactions with teachers and students in schools, fostering peer discussions on digital learning, and offering feedback on digital competence development. Using longitudinal data from 308 pre-service teachers at a German university, the study found that TPK and TPCK beliefs did not develop naturally over the course of a semester. However, competence beliefs became significantly stronger throughout the course of the semester, compared to at the beginning, among students who reported greater satisfaction with the SQD instructional strategies used. Notably, the orchestration of these strategies was critical: it was not the presence of any single strategy, but rather the combined and coordinated use of multiple strategies, that contributed to the development of professional digital competence beliefs in pre-service teachers.

Also focusing on proposed strategies in the SQD model (Tondeur et al., 2012), *Aumann*, *Grassinger*, and *Weitzel* examine the impact of learning environments constructed in accordance with the SQD model, focusing specifically on internship settings as critical components of teacher education. In their longitudinal study, they investigated how pre-service biology teachers' motivational beliefs changed over the course of a practicum using a pre–post design. The sample consisted of 43 pre-service teachers at a German university. Prior to the internship, students received a theoretical introduction, designed and discussed lesson plans incorporating explanatory videos, and created planned video content in collaboration with their peers. During the practicum, the developed lesson plans—including the use of video-based instruction—were implemented in real classroom settings and subsequently reflected upon. The findings indicate that, following the internship and its associated preparatory and reflective phases, pre-service teachers reported increased self-efficacy and more positive attitudes toward the use of technology in the classroom. In addition, students described a stronger motivational orientation toward integrating technology into their future teaching practices.

Johnson, *Schmit*, *Schneider*, *Rossa*, and *Müller* explore the potential of an extracurricular learning environment designed based on SQD principles (Tondeur et al., 2012). In their longitudinal mixed-methods study, the authors examined the effectiveness of a 10-module online course (total of 90 h) on the development of basic and professional digital competencies. The study involved 40 pre-service teachers from one University in Germany. The training addressed a broad range of topics, including the theoretical foundations of digital teaching, ICT applications, legal frameworks, media didactics, and the use of digital teaching materials. The results showed significant increases in participants' technological knowledge (TK), technological content knowledge (TCK), and related competence beliefs. However, no significant changes were observed in participants' technological pedagogical content knowledge (TPCK) competence beliefs, ICT-related value beliefs, or professional digital knowledge. In follow-up interviews, participants reflected on their experiences. While they appreciated the collaborative elements and the personalized nature of the training—particularly the individual feedback—some criticized the lack of practical application and reported that the use of videos failed to fulfill the intended role-modeling function.

Three contributions in this Special Issue focus on the *professional development of in-service teachers* and explore how their digital competencies can be strengthened through different learning experiences. One relevant approach to shaping the content that pre-service and in-service teachers engage with is the use of role models. *Amdam*, *Nagel*, *Njå* and *Forsström* employ this approach by investigating highly digitalized schools, focusing on how experienced teachers in 1:1 settings have perceived effective teaching. The data they considered came from 1505 Norwegian teachers teaching in elementary school or secondary schools. Two key findings emerged from their study: First, classroom management was identified as a critical factor in 1:1 classes; teachers emphasized the importance of combining strategies—building strong relationships with students, providing clear structures, goals, and rules, and leveraging digital tools for instructional oversight. Second, the study revealed that teachers with lower digital competence focused primarily on the availability of resources and organizational aspects, while those with medium to high competence levels placed greater emphasis on classroom management and instructional practices when using technology.

In addition to the relevant content to be discussed and the appropriate strategies for using technology, the effectiveness of further training for in-service teachers was examined. *Annemann*, *Menge*, and *Gerick* investigated in-service teachers' participation in professional development programs related to technologies, and how such participation is associated with teachers' attitudes toward technology, technology usage, and their teaching about technology. Drawing on international cross-sectional data from the international large-scale ICILS study, the authors found that teachers (N = 10.389) who engaged in professional development focused on (a) technology applications, (b) the integration of technology into teaching, (c) subject-specific digital resources, (d) the use of technology for student learning, and (e) personalized learning reported more favorable attitudes toward technology. These teachers also reported more frequent integration of technology into their classrooms and placed greater emphasis on fostering students' digital competencies.

Lastly, *Fütterer*, *Wurst*, and *Goeze* examined the impact of a professional online development program on their digital competencies in Germany. Specifically, the authors investigated the perceived quality of the online professional development course. They integrated active learning elements with feedback, critical reflection through video vignettes, engagement in professional learning communities, opportunities for the practical implementation of content, and reflecting on teaching experiences. In their study, which had pre–post design, the authors examined the effects of this one-month online program (totaling 18 h) on 76 in-service teachers' self-reported satisfaction, perceived competencies, and knowledge. Results from the pre- and post-assessments indicated that participants perceived the program as meaningful, particularly valuing the interactive components and video-based learning scenarios. However, objective assessments of knowledge and abilities did not show significant changes over time.

5. Summary of Insights on Empowering Teacher Professionalization with Digital Competencies

The contributions in this Special Issue reveal that fostering digital competencies in teacher education and professional development requires coordinated attention to both the processes of learning—that is, what is to be learned—and how instruction can be structured to facilitate learning or professional development. The following sections highlight evidence-based core components of instructional quality that were used to foster digital competencies across studies—components that are reflected in the MAIN-TEACH and SQD models and that are here further differentiated bearing in mind the empirical findings presented in this Special Issue. By synthesizing these findings, this Special Issue

contributes to a clearer understanding of what constitutes effective professional learning and proposes concrete directions for the development of research-informed and evidence-based training programs for both pre-service and in-service teachers.

Aligning Curricula with Professional Realities. Since instructional processes are closely aligned with the content being taught, the selection and relevance of digital learning content play a pivotal role in shaping teacher professionalization. This focus directly relates to one of the key instructional quality dimensions identified in the MAIN-TEACH model—*selecting and addressing the content*—which emphasizes that the choice, clarity, and contextual relevance of content are central to enabling meaningful learning processes. The findings in this Special Issue underscore the importance of integrating domain-specific digital content into teacher education and professional development—ranging from various available ICTs, AI, the pedagogical use of ICT or the legal aspects of ICT use (see Runge et al., 2025; Fütterer et al., 2025; Annemann et al., 2025). This content and the curriculum of teacher education should, as suggested by the authors, be continuously updated to reflect technological developments, emphasizing the need for lifelong professional learning (Amdam et al., 2024; Johnson et al., 2024).

Designing authentic learning environments. In addition to the selection and integration of relevant content, a key consideration is the design of learning environments that are pedagogically authentic—that is, environments that are meaningful and realistic from the perspective of (future) teachers (Tondeur et al., 2012). Scholars in this Special Issue have addressed authenticity by using simulations that allow students to develop their skills in lifelike scenarios without real-world consequences (Roeben et al., 2025), as well as by providing opportunities to practice the use of technology in actual classroom settings, such as through internships (Aumann et al., 2025; Fütterer et al., 2025; Hirsch & Rubach, 2024).

Connecting Theory, Empirical Evidence and Practice. The importance of connecting theory and practice emerges as a core factor to support pre-service and in-service teachers (see Tondeur et al., 2012). Pre-service teachers reported struggling to recognize the relevance of theoretical input when practical application of technology use was lacking (see Johnson et al., 2024). Teacher education should enable participants to learn not only from theory, but also apply knowledge, for example by trying to use ICT (see Hirsch & Rubach, 2024; Fütterer et al., 2025) and learn from the practices of other teachers, including (staged) video vignettes or visiting exemplary schools using ICT and with experienced colleagues (see Aumann et al., 2025; Amdam et al., 2024; Hirsch & Rubach, 2024). Although many studies emphasize the importance of linking theory and practice, they rarely integrate empirical findings in a way that allows participants to engage with research-based evidence. This suggests a missed opportunity to foster evidence-informed professionalism in teacher education—an aspect that should be emphasized more strongly in this context.

Provide Learning from theory, planning and implementation to reflection. What is evident across many of the studies included in this Special Issue is that the learning process follows a similar structure which closely resembles the learning cycle for teacher education proposed by McDonald et al. (2013). The following phases are proposed by McDonald: introducing and learning about the activity (e.g., through modeling), preparing for and rehearsing the activity (e.g., through collaborative planning), enacting the activity with students (e.g., by co-teaching), analyzing enactment and moving forward (e.g., through video analysis). In the studies included in this Special Issue, participants first receive a theoretical input, which they are then expected to apply independently (see Aumann et al., 2025; Fütterer et al., 2025). In most cases, this is achieved by developing lesson plans that allow for pre-service or in-service teachers to incorporate the newly acquired knowledge into their own teaching practices. These lessons are subsequently implemented in practice and, where possible, reflected upon. In several studies, participants were given the opportunity to practice

using technology in their own time, yet this aspect was rarely addressed explicitly or discussed as a deliberate feature of instructional design. The study by Johnson et al. (2024) further supports the importance of planning technology use in lessons and putting this into practice as pre-service teachers criticized the fact that, although theoretical input was provided, opportunities for practical application were missing. This focus directly relates to two further instructional quality dimensions identified in the MAIN-TEACH model, cognitive activation and supporting practice, which emphasize that learning processes are most effective when learners are intellectually challenged and provided with opportunities to apply and consolidate what they have learned. These steps also relate to Tondeurs' idea of instructional design, which states that student teachers need to learn to apply technology in class (Tondeur et al., 2012).

Feedback and Reflection. As described in the MAIN-TEACH model, it is also important to assess learners formatively, i.e., to not only to monitor their learning progress, but also to provide instruction and timely, constructive feedback that supports ongoing development. Studies in this Special Issue indicate that, for learners, receiving feedback on their learning progress, e.g., after engaging in practice, is effective for their competence development (see also Tondeur et al., 2012), but also that they critically reflect on their own teaching experiences. The emphasis on reflection as a key component of the learning process within teacher education and professional development is supported by several studies in this Special Issue (see Aumann et al., 2025; Hirsch & Rubach, 2024; Johnson et al., 2024; Fütterer et al., 2025). Feedback and reflection, as also described by McDonald, either occur at the end of the learning process—after newly acquired content has been applied (see Aumann et al., 2025)—or are implemented formatively throughout the learning process to guide and support ongoing development (Fütterer et al., 2025; Johnson et al., 2024; Hirsch & Rubach, 2024).

Implementation of different stakeholders. Role models emerged across several studies as key elements in fostering digital competence development. As highlighted by Tondeur et al. (2012), the use of role models is one of the central strategies in the SQD model for supporting professional learning. The findings in this Special Issue suggest that role models are most effective when learners are given opportunities to observe digital teaching practices not only through video vignettes, but through structured, authentic learning environments—such as those involving peer observations, mentoring, and in-person modeling within internships (see Aumann et al., 2025; Hirsch & Rubach, 2024). This particularly concerns teachers being not only role models but also peers. Equally important, however, is that both pre-service and in-service teachers are given the opportunity to try implementing their ideas directly with students (see Aumann et al., 2025; Hirsch & Rubach, 2024). While this aspect is less related to the concept of role modeling, it is crucial for ensuring the authenticity of learning environments (see Tondeur et al., 2012), allowing learners to connect theoretical and empirical input with real-world teaching experiences. Both aspects—learning through role models and engaging in authentic teaching experiences—can be understood as forms of support for active engagement within the MAIN-TEACH framework.

Collaborative learning. Tondeur et al. (2012) emphasize the importance of collaborative learning settings in teacher education as a key strategy for fostering digital competencies. The goal is to enable pre-service teachers to engage in meaningful dialog with peers, discuss and apply newly acquired knowledge, and learn from one another through joint exploration and practice. For in-service teachers, the concept of professional learning communities plays a central role (Amdam et al., 2024; Fütterer et al., 2025). Within these communities, participants collaboratively reflect on the implementation of technology, exchange ideas, and critically discuss the challenges and successes observed in practice. For pre-service teachers, collaborative formats often resemble communities of practice, in

which students are exposed to the ideas of their peers, engage in shared discussions, and co-develop solutions (Johnson et al., 2024; Hirsch & Rubach, 2024). Although the dimension of collaboration is not explicitly addressed in the MAIN-TEACH model, the findings of this Special Issue emphasize its empirical relevance as a content-specific teaching strategy, particularly in preparing teachers to use ICT effectively in their professional practice.

6. Future Steps Toward Effective Support in Teacher Digital Professionalism

The contributions in this Special Issue provide empirical evidence that aligns with and expands upon key assumptions of established models such as MAIN-TEACH and SQD. Across the contributions included here, there is consistent evidence that the effectiveness of professional learning environments depends not on individual strategies but rather on their systematic orchestration in a coherent, developmental structure (see Hirsch & Rubach, 2024). These models also offer a valuable orientation for future research, several directions of which are suggested by the authors themselves.

When reflecting upon the contributions to this Special Issue, it is interesting that limited attention has been paid by the researchers included here to the generic-content dimensions of high-quality teaching, i.e., classroom and time management and socio-emotional support. This might have been the case because studies on teaching quality and research on fostering teachers' digital competencies is often not interconnected—neither theoretically nor empirically. This might be because the models of high-quality teaching have been conceptualized to describe the prerequisites of fostering students' rather than teachers' learning outcomes mostly at the K-12 stage (see Praetorius & Gräsel, 2021). Many of the studies in this Special Issue draw on ideas that are closely aligned with established models such as MAIN-TEACH or SQD, even though they do not always explicitly reference these frameworks. From our perspective, making these theoretical foundations more explicit and connecting them through a transdisciplinary lens could be highly beneficial. It would allow for a more integrated understanding of high-quality teaching to be developed, and it would be useful in informing the systematic design of teacher education programs aimed at fostering digital competence. Moreover, although the importance of adaptivity and differentiation is acknowledged in several contributions, these dimensions are often discussed rather than empirically investigated in depth (Annemann et al., 2025; Amdam et al., 2024; Aumann et al., 2025; Hirsch & Rubach, 2024). However, the contributions suggest that heterogeneity in teachers' prior knowledge, interests, and needs must be taken seriously (e.g., Rahden et al., 2025). This suggests that differentiation should go beyond adaptations of materials or structures within a single learning environment and instead involve the design of diverse environments tailored to specific content areas and learning objectives related to digital competence. To obtain knowledge about the diversity of needs, simulation environments help to identify needs through formative assessments without the risk of real-life consequences (Roeben et al., 2025).

This Special Issue has offered differentiated views on various aspects of professionalization in teacher education and professional development, providing valuable insights into how digital competencies can be supported. While several studies contribute to our understanding of motivational beliefs—such as self-efficacy, perceived usefulness, and intention to use digital tools—there is still limited empirical knowledge on how to effectively foster knowledge and practical skills, particularly among in-service teachers.

In conclusion, the contributions in this Special Issue can be used to inform teacher education and teacher professional development about central preconditions to foster teachers' digital competencies systematically, and they also provide knowledge about effective design-principles as. All scholars provided empirical evidence for the central prerequisites for the high-quality promotion of pre-service and in-service teachers' digital competencies,

that is (a) aligning curricula with professional realities, (b) designing authentic learning environments, (c) connecting theory, empirical evidence and practice, (d) providing learning from theory, planning, and implementation to reflection, (e) providing feedback and encouraging reflection, (f) considering different stakeholders, as well as (g) nurturing the conditions for collaborative learning and (h) and the way they are combined and orchestrated to provide high-quality learning opportunities. Thus, we have compiled research on high-quality teaching for the development of teachers' digital competencies. These joint perspectives can be highly fruitful in the endeavor to better understand how the digital competencies of educators can be fostered effectively.

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