Can we foster pre-service teachers' competences for digital collaboration?

Annika Ohle-Peters*, Ulrich Ludewig and Nele McElvany

Center for Research on Education and School Development, TU Dortmund University, Dortmund, Germany

Digital collaboration in schools is becoming increasingly important in educational processes—for teachers as well as for students. Teachers' competences, including professional knowledge (e.g., technological-pedagogical content knowledge; TPCK), attitudes (e.g., regarding the usefulness of digital collaboration), and their motivational orientations (e.g., intrinsic motivation and self-efficacy beliefs), are essential prerequisites for digital collaboration within the teaching staff and for teaching students how to learn collaboratively using digital media. Teacher education at universities plays a crucial role in the development of teachers' professional competences, yet little is known about how teachers' digital collaboration competences can be fostered effectively. Hence, the research aim was to investigate (a) the development of pre-service teachers' TPCK, attitudes, and motivational orientations toward digital collaboration in general, (b) analyze the development of their intentions to use digital collaboration in the future, and (c) evaluate the effectiveness of interventions focused on digitally collaborative learning. In this multi-cohort quasi-experimental study with pre-post design, $N = 439$ students participated either in intervention group (IG) courses ($n_{IG} = 351$) explicitly fostering digital collaboration or in regular university courses without explicit fostering of digital collaboration, who served as a control group (CG; $n_{CG} = 88$). Results of conditional latent three-level growth models indicate a positive development of pre-service teachers' TPCK and their intentions to use digital collaboration. This research contributes to the highly relevant question of how to prepare teachers for increasingly digitalized teaching and learning settings in school.

KEYWORDS

teacher competences, digitalization, digital collaboration, professional knowledge, teacher attitudes, teacher motivation, TPACK

1 Introduction

Digital competence is a key competence for the 21st century (Vuorikari et al., 2022). Digital teaching and learning have become more and more relevant, not only due to the COVID-19 pandemic, resulting in new teaching methods and new ways of communication within the classroom as well as within the teaching staff. Systematic reviews show an increasing body of research on teachers' digital competences and the need for fostering (pre-service) teacher's competences to deal with and teach with digital media (Basilotta-Gómez-Pablos et al., 2022; Gutiérrez-Ángel et al., 2022). Digital technologies, including computers and digital platforms, provide various possibilities for collaboration in the school context. Also, digital collaboration is widely considered an important aspect of digital competence in general (van Laar et al., 2017) and of teachers' professional digital competence in particular (Skantz-Åberg et al., 2022). Furthermore, digital collaboration has potential for teachers in several areas, such as professionalization (Redecker and Punie, 2017), synchronous and asynchronous

problem-solving (Vuorikari and Brečko, 2013), or joint development of lesson plans (Hrastinski, 2021). Consequently, teachers need to be prepared to work together digitally in effective ways in order to improve teaching and learning processes. According to established and empirically tested models of teachers' professional competence (professional competence in general: Baumert and Kunter, 2013; digital competences: Mishra and Koehler, 2006; Skantz-Åberg et al., 2022), teachers' professional knowledge (here: Technological Pedagogical Content Knowledge, TPCK), attitudes (e.g., regarding the usefulness of digital collaboration), and their motivational orientations (e.g., intrinsic motivation and self-efficacy to collaborate digitally) are vital components of teachers' competence, which in turn is predictive for teachers' intentions to use digital collaboration. A broad body of evidence indicates that the first phase of teacher education at universities is essential for the development of (pre-service) teachers' professional competences (Blömeke et al., 2008; Lachner et al., 2021; Tatto, 2021). Consequently, university courses provide an ideal opportunity to promote pre-service teachers' competences for digital collaboration. The present study evaluates interventions to foster pre-service teachers' digital collaboration in different subject didactics courses at a German university, investigating the development of pre-service teachers' competences and their intentions to engage in digital collaboration in the future.

2 Theoretical background

2.1 Digital collaboration among teachers

The importance of digital collaboration is increasingly recognized across various sectors of society in general and educational systems specifically. Especially since the COVID-19 pandemic, the opportunities and challenges of digital teaching and learning processes have been discussed and empirically investigated worldwide. Within the European Framework for the Digital Competence of Educators (DigCompEdu), digital collaboration is identified as a crucial component of teachers' digital competencies (Redecker and Punie, 2017). This emphasis on digital collaboration underscores its significance for addressing the demands and complexities of professional educational practice. Distinct from teacher cooperation, collaboration is defined as "a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a sheared conception of a problem" (Roschelle and Teasley, 1995, p.70). Teacher collaboration can be regarded as a continuum from working individually on the one end and intense deep levels of collaboration such as co-construction on the other (Fussangel and Gräsel, 2010; Vangrieken et al., 2015). There is sound empirical evidence that teacher collaboration is positively associated with instructional quality and student achievement (e.g., Goddard et al., 2007; Ronfeldt et al., 2015).

Digital technologies offer significant potential to enhance the quality of collaboration among teachers, e.g., by providing for synchronous and asynchronous communication, sharing resources or engaging in joint tasks, collaborative learning processes, or co-construction (Jeong and Hmelo-Silver, 2016). Studies indicate that digital collaboration is associated with higher learning performance, more positive attitudes toward learning and more productive collaboration—for students as well as teachers (Sung et al., 2017).

Moreover, it can be a powerful tool for teacher professionalization and teaching itself, as digital teacher collaboration bears the potential to improve teachers' professional performance by, e.g., sharing best-practice examples not only within schools but within a broader professional network (García-Martínez et al., 2022). However, effective digital collaboration requires specific competencies, underscoring the need to integrate digital technology skills into university teacher training programs (Caena and Redecker, 2019). As such, fostering pre-service teachers' competences for digital collaboration is essential for leveraging the potential of digital technologies in education.

2.2 Teachers' professional competences for digital collaboration and their relevance for teachers' actions

According to established models of teachers' professionalism, competences for digital collaboration include cognitive and motivational components (Baumert and Kunter, 2013; Skantz-Åberg et al., 2022). One core component of teachers' competence is their professional knowledge. In the context of teaching with digital technologies, the widely established TPACK model describes *Technological Pedagogical Content Knowledge (TPCK)* as a special form of knowledge that goes beyond content knowledge, pedagogical knowledge, and technology knowledge (Mishra and Koehler, 2006). Being subject-independent, TPCK includes knowledge about using technologies, instructional techniques using digital technology and knowledge about student learning (Mishra and Koehler, 2006). Research has repeatedly shown positive relations between teachers' TPCK and student achievement in different subjects and grades (e.g., Akturk and Ozturk, 2019; Duan et al., 2022) and it is therefore an important objective for university teacher training. TPCK can be an important prerequisite for using digital technologies for collaboration in later professional life (Maor, 2017).

Besides professional knowledge, teachers' attitudes play an important role for their professional behavior, as they influence the subjective perception of situations and impact teachers' actions on an unconscious level (Staub and Stern, 2002). Attitudes can also moderate the use of professional knowledge and skills (Gess-Newsome, 2015). According to the (situated) expectancy-value-model, the utility value, as a component of the subjective task value, is one factor that impacts individuals' choices and actions (Eccles and Wigfield, 2020; Wigfield and Eccles, 2000). When a specific task or goal is considered valuable or useful, individuals are more likely to engage in it. Concerning digital collaboration, teachers' *attitude toward the usefulness* of digital technology positively predicts their intentions to participate in technology-related professional development and collaboration (Fütterer et al., 2023; Vangrieken et al., 2015).

Alongside cognitive components of professional competences, affective-motivational aspects are equally important for teachers' professional performance. Motivational orientations such as intrinsic motivation and self-efficacy beliefs are vital motivational components of teachers' professional competences (Baumert and Kunter, 2013). Following Ryan's and Deci's self-determination theory, *intrinsic motivation*, i.e., the joy of performing an activity itself, goes hand in hand with self-determined action (Ryan and Deci, 2017, 2020). Consequently, intrinsic motivation is considered an important prerequisite for multiple aspects of professional success, e.g., for the

quality of teachers' professional actions, their well-being, and student outcomes (Keller et al., 2016). Studies on teachers' intrinsic motivation with regard to digital collaboration are scarce. Yeung et al. (2014) found that mastery goal orientation positively related to (pre-service) teachers' use of digital technologies, while Kolleck (2019) investigated teacher collaboration in general and discovered a bidirectional association between teachers' motivation and teacher collaboration. Another motivational orientation, teachers' *self-efficacy beliefs*, as a conviction that one is able to successfully master tasks and a further component of motivational orientations, also correlates with teacher performance, teacher well-being and student performance (Bandura, 1978; Zee and Koomen, 2016). There is empirical evidence that teachers with higher self-efficacy beliefs are more likely to share information in digital collaboration settings than teachers with low self-efficacy beliefs (Richter et al., 2022).

To the best of our knowledge, no empirical studies to date simultaneously investigate all of the aforementioned aspects of teacher professionalism with regard to digital collaboration, meaning that the question of the associations between (pre-service) teachers' competences and their performance remains unanswered. In their model of teacher competence as a continuum, Blömeke et al. (2015) argue that the aforementioned cognitive and affective-motivational dispositions are prerequisites of teachers' situation-specific skills (e.g., making decisions on how to act in a certain situation) and performance. Furthermore, the theory of planned behavior states that individuals' background factors, such as knowledge, attitudes and emotions, predict a person's intentions, which in turn precede actual behavior (Ajzen and Albarracin, 2007; Dierendonck et al., 2024). Hence, referring back to digital collaboration, there is strong theoretical and empirical evidence for the importance of teachers' aforementioned competences for their *intentions to use digital collaboration* in their professional life and for actually engaging in digital collaboration.

2.3 Relevance of teacher education and interventions for pre-service teachers

Teacher education at universities plays a crucial role in the development of teachers' professional competences (Blömeke et al., 2008). A curriculum of subject-specific courses, subject-didactic courses and general pedagogical components—the proportions vary across teacher training programs (e.g., for future elementary school teachers or future upper secondary school teachers)—provides learning opportunities to foster pre-service teachers' cognitive and non-cognitive competences. A range of intervention studies demonstrate the effectiveness of measures to promote digital competences among pre-service teachers within this first phase of teacher education. In their qualitative study, Reisoğlu and Çebi (2020) showed that pre-service teachers attending a 70-h training on digital competences rooted in the DigComp framework (Redecker and Punie, 2017) reported higher knowledge and skills regarding communication and collaboration via digital technologies. It should be critically noted that there was no control group in the study design and the effects can therefore not be attributed to the intervention alone. However, Lachner et al. (2021) evaluated the effectiveness of a 3-week TPACK intervention in a quasi-experimental study and found positive effects on pre-service teachers' TPACK (here: Technological

Pedagogical Content Knowledge) and their technology-related self-efficacy. However, a quasi-experimental study by Bertram et al. (2023) indicated that a 2-day workshop with pre-service and in-service teachers could increase self-efficacy in teaching with digital technology in all participants, but no effects were found for technological-pedagogical knowledge and attitudes. Summarizing, empirical evidence on the effectiveness of interventions to foster pre-service teachers' digital competences mostly focuses on isolated aspects of competencies rather than comprehensively addressing both cognitive and motivational components, does not always specifically address digital collaboration, and findings are not consistent. Consequently, the present study aims to evaluate the effects of interventions developed and implemented within subject-didactic courses on pre-service teachers' digital collaboration.

3 Research questions and hypotheses

Given the importance of teacher education for the development of pre-service teachers' professional competences and the growing relevance of digital competences, the present study aims to investigate (a) the development of pre-service teachers' TPCK, attitudes, and motivational orientations toward digital collaboration as core aspects of their professional competence as well as (b) their intentions to use digital collaboration as in-service teachers. Furthermore, we evaluate the effectiveness of interventions promoting pre-service teachers' digital collaboration. Concretely, three research questions guided the present study:

RQ1: How do pre-service teachers' competences for digital collaboration develop over the course of a semester?

H1: We expect a positive development of (a) technological-pedagogical content knowledge, (b) attitudes toward the use of digital collaboration, and (c) motivational orientations toward digital collaboration among all pre-service teachers.

RQ2: Is there a change in pre-service teachers' intentions to use digital collaboration (idealistic and realistic) in the course of one semester?

H2: Analog to hypothesis H1, we also expect a positive development in pre-service teachers' intentions to collaborate digitally in the future.

RQ3: What differences in competence development and intentions to use digital collaboration can be seen between pre-service teachers who attend courses that explicitly promote digitally collaborative work (intervention group, IG) and pre-service teachers attending regular courses (control group, CG)?

H3: It is assumed that the pre-service teachers' competences and intentions to use digital collaboration develop more positively in the IG than in the CG.

4 Methods

4.1 Sample and design

Data originated from the project "Collaborative teaching and learning with digital media in teacher education: mobile—professional—inclusive" (K4D, funded by the German Federal Ministry of Education and Research). Altogether, $N = 439$ pre-service

TABLE 1 Overview of samples in intervention group (IG) and control group (CG).

	n	Age	% Female	% Bachelor studies	% aspired teaching degree: university-preparatory secondary school
		M (SD)			
IG	351	23.6 (4.48)	72.36	80.01	29.06
CG	88	23.0 (3.42)	62.50	73.86	28.41

None of the differences between IG and CG are statistically significant.

TABLE 2 Overview constructs used for assessment.

Construct	Source	No. of Items	Sum score range	Cronbach's alpha (t1/t2)
TPCK[1]	Lorenz et al. (2017)	5	5–20	0.88/0.88
Attitude toward the usefulness of digital technology[2]	Vogelsang et al. (2019)	8	8–32	0.84/0.88
Intrinsic motivation for digital collaboration[2]	Mullis et al. (2016)	5	5–20	0.88/0.90
Self-efficacy for digital collaboration	Adapted from Gebauer et al. (2013)	5	5–20	0.81/0.83
Intention to use digital collaboration (idealistic)[3]	Own development	6	6–24	0.72/0.82
Intention to use digital collaboration (realistic)[4]	Own development	6	6–24	0.81/0.86

[1]Likert scale ranging from 1 = "not applicable at all" to 4 = "totally applicable"; [2]Likert scale ranging from 1 = "totally disagree" to 4 = "totally agree"; [3]Likert scale ranging from 1 = "very reluctant" to 4 = "very gladly"; [4]Likert scale ranging from 1 = "very unlikely" to 4 = "very likely".

teachers participated voluntarily at both measurement points, giving informed consent as required by the local data protection law. The interventions and thus also the survey took place in the context of the according courses. 81.05% of the courses (lectures and seminars) were compulsory for the students; accordingly, this was an opportunity sample. Participants differed regarding their degree program (bachelor vs. master studies) as well as the type of teaching degree they were set to attain (elementary school vs. non-university preparatory secondary school vs. university-preparatory secondary school). Sample information is provided in Table 1.

Data assessment took place between 2020 and 2023 at TU Dortmund University, Germany, with five cohorts of pre-service teachers. In a pre-post-control group design, pre-service teachers attended either didactic courses that used and explicitly fostered digital collaboration (intervention group, IG) or regular didactic courses without digital collaboration (control group, CG). The interventions were developed in different subject didactic courses (Chemistry, English, Mathematics, Music, Social Science, and Physical Education) on the basis of a common definition of digital collaboration:

"Digitally collaborative work is an interactive and discursive form of collaboration using digital media in which the group members…
…feel individually responsible for the joint result,
…are dependent on each other to achieve the goal,
…enter into discussion and exchange in order to negotiate different perspectives and meanings or to negotiate common perspectives and meanings,
…help and support each other in their work in the best possible way,
…not only work alone, but together as a team,
…make joint decisions on their goals and on the work process meeting (jointly agree, exchange, coordinate and reflect)" (Hußmann et al., 2020).

Hence, in the IG courses, students worked together on joint problems using digital technologies such as Moodle, Padlet, or video conferencing. While the focus in Mathematics courses was on collaboratively solving mathematical problems, for example, joint movement analyses were carried out in Physical Education courses and soundscapes were created together in Music courses. The interventions in the IG courses differed in duration and intensity across subjects (minimum: two sessions with intervention per semester, maximum: several weeks of intervention) as well as in terms of the form of collaboration (synchronous vs. asynchronous). Pre-service teachers in the control group did not receive tasks, specially designed to collaborate digitally. Nevertheless, also regular seminars include a certain degree of collaboration. In comparison to the IG, such collaboration is not specially designed to foster pre-service teacher's competences for digital collaboration. To evaluate the effectiveness of the interventions, data was collected via online questionnaires at the beginning of the semester (t1) and at the end (t2) in both IG and CG courses.

4.2 Instruments

Pre-service teachers' competences for digital collaboration and their (idealistic and realistic) intentions to use digital collaboration in their future profession as teachers were assessed using established questionnaires and self-developed scales. Table 2 provides an overview of the assessed constructs, original sources, sum score range, and internal consistency, measured by Cronbach's Alpha, for t1 and t2.

Altogether, internal consistency was good for all constructs at both measurement points.

4.3 Analyses

To answer the research questions, a hierarchical linear modeling approach was employed, utilizing a multilevel latent Rasch model as delineated by Doran et al. (2007), to evaluate changes in pre-service teachers' competences for digital collaboration. The analysis was

conducted using the "lme4" package within the R statistical software environment. The quasi-experimental study design incorporated a hierarchical structure, introducing a random intercept to account for variability at the course level and a random slope to capture the development (pre-intervention vs. post-intervention) within each course. Further, the model included three fixed effects: (1) a group effect, quantifying the initial discrepancy between the intervention and control groups as assessed during the pre-measurement; (2) a time effect, measuring the development observed between the pre-and the post-measurement in the IG and CG together; and (3) a treatment effect, articulating the interaction between the development (pre vs. post) and the intervention group (courses with digitally collaborative teaching intervention vs. regular didactic courses without digital collaboration). The magnitude of the treatment effect delineates the degree to which the intervention group yielded a stronger development relative to the control group. The results are reported in terms of standardized regression coefficients.

Additionally, the robustness of the effects was assessed by integrating control variables into the analysis. These control variables incorporate characteristics inherent to the courses under investigation. Specifically, the variables included (1) the level of certification, distinguishing between bachelor's (reference category) and master's level courses; (2) the obligatory nature of the course, differentiating between compulsory (reference category) and elective courses; (3) the type of teaching degree in which participants were enrolled, contrasting primary education (reference category) with other educational specializations; and (4) the instructional format, comparing seminars (reference category) with lectures. The most frequently observed category within each variable was designated as the reference category. Within the analysis, the regression coefficients, adjusted for these control variables, elucidate the effects attributable to students enrolled in compulsory bachelor-level seminars within a primary school teacher education program.

5 Results

5.1 Descriptive results

Descriptive analyses showed that students in the intervention group and the control group differed in their TPCK at the beginning of the semester and numeric results already indicate a more positive development in the intervention group (see results for research question 3). There were no differences between the two groups for the other competence constructs (attitudes and motivational orientations; see results for research question 1). Regarding pre-service teachers' intentions to use digital collaboration in the future, descriptive results indicate more positive intentions of students in the intervention group at the beginning of the semester. Means and standard deviations for each group and measurement point are displayed in Table 3.

5.2 RQ1: development of pre-service teachers' competences for digital collaboration during the semester

The analysis comparing overall pre-and post-measurements over the course of one semester revealed no statistically significant change

TABLE 3 Descriptive results for each construct.

Constructs	Measurement	Group	M	SD
TPCK	pre	Control	13.2	2.5
		Intervention	12.5	2.8
	post	Control	13.8	2.8
		Intervention	13.8	2.5
Attitudes toward digital collaboration	pre	Control	23.9	4.2
		Intervention	24.0	3.9
	post	Control	24.1	4.2
		Intervention	24.6	4.0
Intrinsic motivation for digital collaboration	pre	Control	14.0	3.1
		Intervention	14.4	3.0
	post	Control	13.8	3.2
		Intervention	14.3	3.1
Self-efficacy for digital collaboration	pre	Control	14.3	2.6
		Intervention	14.4	2.4
	post	Control	14.6	2.8
		Intervention	14.8	2.3
Intention to use digital collaboration (idealistic)	pre	Control	17.6	3.4
		Intervention	18.1	3.3
	post	Control	18.4	3.9
		Intervention	18.2	3.6
Intention to use digital collaboration (realistic)	pre	Control	15.8	3.2
		Intervention	16.5	3.2
	post	Control	16.8	3.8
		Intervention	16.9	3.6

in any of the competence constructs. This outcome suggests that, within the parameters of this study and the measurement interval employed, the intervention or the passage of time did not appreciably influence the pre-service teachers' TPCK, their attitudes toward digital collaboration, or their motivational orientations toward such collaboration (see Table 4).

5.3 RQ2: development of pre-service teachers' intentions to use digital collaboration in the future

An overall increase in idealistic and realistic intentions to engage in digitally collaborative instruction was observed, as seen in Table 4.

Statistically significant growth was recorded in the idealistic intention to engage in digitally collaborative instruction, as evidenced by a regression coefficient $\beta = 0.18$ (0.07). Similarly, the realistic intention to engage in digitally collaborative instruction demonstrated a significant rise, with $\beta = 0.20$ (0.08). These increments remained substantial and robust when adjusting for various course characteristics in the analysis. This suggests that, over time, there was not only a notable enhancement in the idealistic predisposition toward use of digitally collaborative tools in instructional settings but also an

TABLE 4 Results of the hierarchical latent Rasch model estimating the group, time, and treatment effect.

RQ	Construct	Effect	Without control variables			With control variables		
			β	se	p	β	se	p
1/3	TPCK	Group	**−0.21**	**0.10**	**0.031**	**−0.20**	**0.10**	**0.037**
		Time	0.17	0.09	0.061	0.16	0.10	0.098
		Treatment	**0.21**	**0.10**	**0.037**	**0.22**	**0.10**	**0.027**
	Attitudes toward digital collaboration	Group	0.02	0.08	0.803	0.03	0.08	0.709
		Time	0.04	0.07	0.618	−0.03	0.08	0.715
		Treatment	0.06	0.08	0.433	0.06	0.08	0.429
	Intrinsic motivation for digital collaboration	Group	0.10	0.10	0.293	0.13	0.10	0.186
		Time	−0.06	0.08	0.445	−0.13	0.09	0.157
		Treatment	0.04	0.09	0.689	0.03	0.09	0.758
2/3	Self-efficacy for digital collaboration	Group	0.04	0.09	0.620	0.04	0.09	0.685
		Time	0.09	0.08	0.265	0.07	0.09	0.444
		Treatment	0.04	0.09	0.661	0.07	0.09	0.466
	Intention to use digital collaboration (idealistic)	Group	0.11	0.08	0.189	0.12	0.08	0.142
		Time	**0.18**	**0.07**	**0.008**	**0.15**	**0.07**	**0.039**
		Treatment	**−0.15**	**0.07**	**0.044**	**−0.15**	**0.08**	**0.042**
	Intention to use digital collaboration (realistic)	Group	**0.15**	**0.08**	**0.049**	**0.15**	**0.08**	**0.045**
		Time	**0.20**	**0.08**	**0.011**	**0.23**	**0.09**	**0.009**
		Treatment	−0.12	0.09	0.167	−0.12	0.09	0.187

RQ, Research Question. Significant effects ($p < 0.05$) are printed in bold.

increase in the realistic intention to implement such tools, irrespective of the specific nature or type of course attended.

5.4 RQ 3: differences between intervention group and control group

Within the scope of research question 3, two statistically significant treatment effects were discerned (see Table 4). Firstly, an analysis pertaining to Technological Pedagogical Content Knowledge (TPCK) unveiled a treatment effect in the anticipated direction. This effect indicates that courses engaging in digitally collaborative practices yielded a more pronounced augmentation in TPCK relative to control courses. Nonetheless, it is imperative to acknowledge the presence of an equally significant difference between the intervention group and the control group prior to the intervention phase (t1). This discrepancy implies that, although the intervention courses saw an increase in TPCK over the course of the semester, this brought them in line with the TPCK levels of the control group, rather than surpassing them. Secondly, the analysis revealed a statistically significant treatment effect regarding the idealistic intention to use digitally collaborative tools; however, the direction of this effect was contrary to expectations. Participants in courses explicitly engaging in digitally collaborative practices exhibited a lower intention to use such practices in the future. This outcome suggests a paradoxical effect where exposure to and participation in digitally collaborative activities may have tempered participants' enthusiasm for or perceived utility of these practices for future teaching contexts.

Both the first (pertaining to TPCK) and the second (concerning the idealistic intention to use digitally collaborative practices)

statistically significant treatment effects were robust to the adjustments made for course characteristics.

6 Discussion

In this study, we explored the impact of interventions aimed at enhancing pre-service teachers' competences for digital collaboration within subject didactics courses at a German university. In light of the increasing importance of digital competence as a key skill for the 21st century, and the growing relevance of digital teaching and learning methods post-COVID-19, our findings present a nuanced view of such interventions' effectiveness. It also adds to the growing body of research on pre-service teachers' digital competences (Basilotta-Gómez-Pablos et al., 2022). Particularly against the background of pre-service teachers perceiving their training in digital skills as rather inadequate (Instefjord and Munthe, 2017), the study presented here makes a contribution to improving these skills in university education.

6.1 Core findings

Focusing on cognitive as well as non-cognitive aspects of teachers' professional competences, our analysis revealed no statistically significant changes in pre-service teachers' technological-pedagogical content knowledge (TPCK), attitudes toward digital collaboration, or motivational orientations toward digital collaboration from pre-to post-measurement for the whole sample (research question 1). This suggests that the short-term intervention may not have been sufficient to effect noticeable changes in these complex constructs. A possible

explanation for the stagnation in competence aspects during a semester could be the variety of individual and institutional factors (e.g., motivational orientations of technical support) that influence the development of digital competencies (Kholid et al., 2023; Lachner et al., 2021). In addition, data collection in the first cohorts took place during the COVID-19 pandemic, when university courses were largely held digitally. This forced pre-service teachers to use digital media for communication and to participate in university courses, potentially weakening the effect of interventions focused on fostering digital collaboration. However, there was a significant positive development in pre-service teachers' TPCK in the intervention group.

Regarding research question 2, we observed a statistically significant increase in both idealistic and realistic intentions to use digital collaboration over time for all participants, indicating a growing openness to digital collaboration methods among participants, independent of course characteristics. Accordingly, it would be important to create favorable conditions for digital collaboration in the second phase of teacher training (post-graduate student teaching). In addition to technical equipment, opportunities to practice digital collaboration are also important factors that influence teachers' willingness to collaborate (e.g., Chen et al., 2014).

Focusing on the effectiveness of the intervention (research question 3), two significant treatment effects were identified that were contrary to expectations. Firstly, while the intervention group showed an increase in TPCK, this was enough to bring their competencies in line with those of the control group, rather than surpass them. A possible explanation for this effect is that students who perceived greater improvement were more likely to participate in the post-measurement. Interpreted positively, this finding shows that the intervention potentially contributed to reducing the gap in pre-service teachers' TPCK. Differences in intervention types, intervention durations or learning environments are known to affect the effects of TPCK interventions (Ning et al., 2022), but course characteristics were controlled for in our analyses. Secondly, and more unexpectedly, the intervention group displayed a reduced intention to use digitally collaborative practices in the future. One explanation for this result could be the implementation of group work within the interventions. Underperforming team members are a not uncommon phenomenon in group work and they might have negative impacts on other group members (Jassawalla et al., 2009). Anyway, this paradoxical outcome suggests that while the interventions may enhance specific competences, they might simultaneously temper enthusiasm for future use of these digital practices, possibly due to unmet expectations or challenges encountered during implementation.

6.2 Limitations and implications

Despite the methodological strengths of the present study, there are some limitations to be discussed—especially in light of the effects not found in the intervention on important aspects of pre-service teachers' competences. First, participant drop-out from pre-to post-measurement must be viewed critically, even though the course instructors gave students class time to answer the questionnaire. On the positive side, there were no statistically significant differences between participants with and without drop-out in terms of age, gender distribution, educational stage or type of teaching degree. Secondly, the first data collection period took place in fall 2021. At that time, the majority of

university courses had been held digitally for three semesters. For our study, this means that the students were already used to using digital media for communication or to participate in courses and we were therefore unable to create a control group without treatment in the strict sense. Thirdly, the interventions were very heterogeneous between courses. Although we controlled for course characteristics in our analyses, future analyses could focus on the effects of individual interventions. Unfortunately, the data collected as part of this project does not allow it, but it would be useful to investigate the effectiveness of the duration, intensity, method or software used on pre-service teachers' competence development. Furthermore, the results should be validated on a larger sample, including courses from different universities. Especially against the background that effects significant, but small (Lakens, 2021), the replicability of the findings should be checked, ideally in a randomized controlled field trial, allowing for causal interpretations. Thinking one step further, future research projects should focus on the effects of pre-service teachers' digital collaboration competences on actual collaboration during their later in-service teaching. Longitudinal studies could identify effective interventions to foster relevant competences and investigate the development of digital collaboration competences in all phases of teacher education. Ultimately, the question of the effect of digital collaboration on the quality of teaching and learning processes remains unanswered.

6.3 Conclusion

In conclusion, our findings underscore the complexity of integrating digitally collaborative practices into teacher education and highlight the need for more comprehensive and possibly longer-term strategies to effectively foster digital competences among pre-service teachers. The robustness of the results, even after controlling for course characteristics, suggests that these conclusions are not merely artifacts of specific contexts but indicate broader trends that warrant further investigation and consideration in the development of teacher education curricula.

Data availability statement

The datasets presented in this article are not readily available because the data are not accessible for data protection reasons. Requests to access the datasets should be directed to Annika.Ohle-Peters@tu-dortmund.de.

Ethics statement

Ethical approval was not required for the studies involving humans because the study did not include vulnerable participants. All participants gave informed consent before filling out the questionnaire. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AO-P: Investigation, Project administration, Writing – original draft. UL: Formal analysis, Writing – review & editing. NM:

Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1455074/full#supplementary-material

References

Ajzen, I., and Albarracin, D. (2007). "Predicting and changing behavior: a reasoned action approach" in Prediction and Change of Health Behavior: Applying the Reasoned Action Approach. eds. I. Ajzen, D. Albarracin and R. Hornik (Mahwah, NJ: Erlbaum), 3–21.

Akturk, A. O., and Ozturk, H. S. (2019). Teachers' TPACK levels and students' self-efficacy as predictors of students' academic achievement. Int. J. Res. Educ. Sci. 5, 283–294.

Bandura, A. (1978). Self-efficacy: toward a unifying theory of behavioral change. Adv. Behav. Res. Ther. 1, 139–161. doi: 10.1016/0146-6402(78)90002-4

Basilotta-Gómez-Pablos, V., Matarranz, M., Casado-Aranda, L.-A., and Otto, A. (2022). Teachers' digital competencies in higher education: a systematic literature review. Int. J. Educ. Technol. High. Educ. 19, 1–16. doi: 10.1186/s41239-021-00312-8

Baumert, J., and Kunter, M. (2013). "The COACTIV model of teachers' professional competence" in Mathematics Teacher Education: v. 8. Cognitive Activation in the Mathematics Classroom and Professional Competence of Teachers: Results from the COACTIV Project. eds. M. Kunter, J. Baumert, W. Blum, U. Klusmann, S. Krauss and M. Neubrand (New York, London: Springer), 25–48.

Bertram, V., Baier-Mosch, F., Dignath, C., and Kunter, M. (2023). Promoting pre-and in-service teachers' digital competence by using reverse mentoring. Unterrichtswissenschaft 51, 559–577. doi: 10.1007/s42010-023-00183-0

Blömeke, S., Felbrich, A., Müller, C., Kaiser, G., and Lehmann, R. (2008). EFfectiveness of teacher education. ZDM 40, 719–734. doi: 10.1007/s11858-008-0096-x

Blömeke, S., Gustafsson, J.-E., and Shavelson, R. J. (2015). Beyond dichotomies. Z. Psychol. 223, 3–13. doi: 10.1027/2151-2604/a000194

Caena, F., and Redecker, C. (2019). Aligning teacher competence frameworks to 21st century challenges: the case for the European digital competence framework for educators (Digcompedu). Eur. J. Educ. 54, 356–369. doi: 10.1111/ejed.12345

Chen, M.-W., Wu, C.-C., and Lee, G. C. (2014). "What are teachers concerned about in implementing digital collaboration?" in 2014 International Conference on Teaching and Learning in Computing and Engineering. IEEE, pp. 234–239.

Dierendonck, C., Poncelet, D., and Tinnes-Vigne, M. (2024). Why teachers do (or do not) implement recommended teaching practices? An application of the theory of planned behavior. Front. Psychol. 15:1269954. doi: 10.3389/fpsyg.2024.1269954

Doran, H., Bates, D., Bliese, P., and Dowling, M. (2007). Estimating the multilevel Rasch model: with the lme4 package. J. Stat. Softw. 20. doi: 10.18637/jss.v020.i02

Duan, G., Jia, L., and Chen, H. (2022). The role of English as a foreign language teachers' technological pedagogical content knowledge on English as a foreign language students' achievement. Front. Psychol. 13, 1–18. doi: 10.3389/fpsyg.2022.946081

Eccles, J. S., and Wigfield, A. (2020). From expectancy-value theory to situated expectancy-value theory: a developmental, social cognitive, and sociocultural perspective on motivation. Contemp. Educ. Psychol. 61:101859. doi: 10.1016/j.cedpsych.2020.101859

Fussangel, K., and Gräsel, C. (2010). "Kooperation von Lehrkräften" in utb Schulpädagogik: Vol. 8443. Handbuch Schulentwicklung: Theorie-Forschungsbefunde-

Entwicklungsprozesse-Methodenrepertoire (1. Aufl., pp. 258–260). eds. T. Bohl, W. Helsper, H. G. Holtappels and C. Schelle (Bad Heilbrunn: Klinkhardt).

Fütterer, T., Scherer, R., Scheiter, K., Stürmer, K., and Lachner, A. (2023). Will, skills, or conscientiousness: what predicts teachers' intentions to participate in technology-related professional development? Comput. Educ. 198:104756. doi: 10.1016/j.compedu.2023.104756

García-Martínez, I., Tadeu, P., Montenegro-Rueda, M., and Fernández-Batanero, J. M. (2022). Networking for online teacher collaboration. Interact. Learn. Environ. 30, 1736–1750. doi: 10.1080/10494820.2020.1764057

Gebauer, M. M., McElvany, N., and Klukas, S. (2013). "Einstellungen von Lehramtsanwärterinnen und Lehramtsanwärtern zum Umgang mit heterogenen Schülergruppen in Schule und Unterricht [Attitudes of trainee teachers towards dealing with heterogeneous groups of pupils in schools and lessons]" in Eine Veröffentlichung der Arbeitsstelle für Schulentwicklungsforschung der Universität Dortmund: Vol. 17. Sprachliche, kulturelle und soziale Heterogenität in der Schule als Herausforderung und Chance der Schulentwicklung: IFS-Jahrbuch der Schulentwicklung. eds. N. McElvany, M. M. Gebauer, W. Bos and H. G. Holtappels (Weinheim, Basel: Beltz), 191–216.

Gess-Newsome, J. (2015). "A model of teacher professional knowledge and skill including PCK: results of the thinking from the PCK summit" in Re-examining Pedagogical Content Knowledge in Science Education. eds. A. Berry, P. Friedrichsen and J. Loughran (New York: Routledge), 28–42.

Goddard, Y., Goddard, R., and Tschannen-Moran, M. (2007). A theoretical and empirical investigation of teacher collaboration for school improvement and student achievement in public elementary schools. Teach. Coll. Rec. 109, 877–896. doi: 10.1177/016146810710900401

Gutiérrez-Ángel, N., Sánchez-García, J.-N., Mercader-Rubio, I., García-Martín, J., and Brito-Costa, S. (2022). Digital literacy in the university setting: a literature review of empirical studies between 2010 and 2021. Front. Psychol. 13:896800. doi: 10.3389/fpsyg.2022.896800

Hrastinski, S. (2021). Digital tools to support teacher professional development in lesson studies: a systematic literature review. Int. J. Lesson Learn. Stud. 10, 138–149. doi: 10.1108/IJLLS-09-2020-0062

Hußmann, S., Bosse, I., Fischer, J., McElvany, N., Kranefeld, U., Melle, I., et al. (2020). K4D-Kollaboration-definition und Designprinzipien [K4D-collaboration-definition and design principles]. TU Dortmund.

Instefjord, E. J., and Munthe, E. (2017). Educating digitally competent teachers: a study of integration of professional digital competence in teacher education. Teach. Teach. Educ. Int. J. Res. Stud. 67, 37–45. doi: 10.1016/j.tate.2017.05.016

Jassawalla, A., Sashittal, H., and Sashittal, A. (2009). Students' perceptions of social loafing: its antecedents and consequences in undergraduate business classroom teams. Acad. Manag. Learn. Educ. 8, 42–54. doi: 10.5465/AMLE.2009.37012178

Jeong, H., and Hmelo-Silver, C. E. (2016). Seven affordances of computer-supported collaborative learning: how to support collaborative learning? How can technologies help? Educ. Psychol. 51, 247–265. doi: 10.1080/00461520.2016.1158654

Keller, M. M., Hoy, A. W., Goetz, T., and Frenzel, A. C. (2016). Teacher enthusiasm: reviewing and redefining a complex construct. *Educ. Psychol. Rev.* 28, 743–769. doi: 10.1007/s10648-015-9354-y

Kholid, M. N., Hendriyanto, A., Sahara, S., Muhaimin, L. H., Juandi, D., Sujadi, I., et al. (2023). A systematic literature review of technological, pedagogical and content knowledge (TPACK) in mathematics education: future challenges for educational practice and research. *Cogn. Educ.* 10:2269047. doi: 10.1080/2331186X.2023.2269047

Kolleck, N. (2019). Motivational aspects of teacher collaboration. *Front. Educ.* 4:122. doi: 10.3389/feduc.2019.00122

Lachner, A., Fabian, A., Franke, U., Preiß, J., Jacob, L., Führer, C., et al. (2021). Fostering pre-service teachers' technological pedagogical content knowledge (TPACK): a quasi-experimental field study. *Comput. Educ.* 174:104304. doi: 10.1016/j.compedu.2021.104304

Lakens, D. (2021). The practical alternative to the p value is the correctly used p value. *Perspect. Psychol. Sci.* 16, 639–648. doi: 10.1177/1745691620958012

Lorenz, R., Bos, W., Endberg, M., Eickelmann, B., Grafe, S., and Vahrenhold, J. (Eds.). (2017). Schule digital—der Länderindikator 2017: Schulische Medienbildung in der Sekundarstufe I mit besonderem Fokus auf MINT-Fächer im Bundesländervergleich und trends von 2015 bis 2017 [Schule digital—the 2017 state indicator: Media education in lower secondary schools with a special focus on STEM subjects in a comparison of federal states and trends from 2015 to 2017]. Waxmann. Available online at: https://www.waxmann.com/waxmann-buecher/?no_cache=1&tx_p2waxmann_pi2%5Bbuch%5D=BUC125422&tx_p2waxmann_pi2%5Baction%5D=show&tx_p2waxmann_pi2%5Bcontroller%5D=Buch&cHash=f3d3edee05b94d1b8f92ec9a598dd2ff (Accessed October 25, 2024).

Maor, D. (2017). Using TPACK to develop digital pedagogues: a higher education experience. *J. Comput. Educ.* 4, 71–86. doi: 10.1007/s40692-016-0055-4

Mishra, P., and Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *Teach. Coll. Rec.* 108, 1017–1054. doi: 10.1111/j.1467-9620.2006.00684.x

Mullis, I., Martin, M., Goh, S., and Cotter, K. (2016). TIMSS 2015 encyclopedia: Education policy and curriculum in mathematics and science. Available online at: http://timssandpirls.bc.edu/timss2015/encyclopedia/ (Accessed October 25, 2024).

Ning, Y., Zhou, Y., Wijaya, T. T., and Chen, J. (2022). Teacher education interventions on teacher TPACK: a meta-analysis study. *Sustain. For.* 14:11791. doi: 10.3390/su141811791

Redecker, C., and Punie, Y. (2017). "EUR, scientific and technical research series" in European Framework for the Digital Competence of Educators. ed. Y. Punie, vol. *28775* (Luxembourg: Publications Office).

Reisoğlu, İ., and Çebi, A. (2020). How can the digital competences of pre-service teachers be developed? Examining a case study through the lens of dig comp and DigCompEdu. *Comput. Educ.* 156:103940. doi: 10.1016/j.compedu.2020.103940

Richter, E., Carpenter, J. P., Meyer, A., and Richter, D. (2022). Instagram as a platform for teacher collaboration and digital social support. *Comput. Educ.* 190:104624. doi: 10.1016/j.compedu.2022.104624

Ronfeldt, M., Farmer, S. O., McQueen, K., and Grissom, J. A. (2015). Teacher collaboration in instructional teams and student achievement. *Am. Educ. Res. J.* 52, 475–514. doi: 10.3102/0002831215585562

Roschelle, J., and Teasley, S. D. (1995). "The construction of shared knowledge in collaborative problem solving" in Computer Supported Collaborative Learning. ed. C. O'Malley (Berlin Heidelberg: Springer), 69–97.

Ryan, R. M., and Deci, E. L. (2017). Self-Determination Theory: Basic Psychological Needs in Motivation, Development, and Wellness (Paperback edition). New York, London: The Guilford Press.

Ryan, R. M., and Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: definitions, theory, practices, and future directions. *Contemp. Educ. Psychol.* 61:101860. doi: 10.1016/j.cedpsych.2020.101860

Skantz-Åberg, E., Lantz-Andersson, A., Lundin, M., and Williams, P. (2022). Teachers' professional digital competence: an overview of conceptualisations in the literature. *Cog. Educ.* 9:2063224. doi: 10.1080/2331186X.2022.2063224

Staub, F. C., and Stern, E. (2002). The nature of teachers' pedagogical content beliefs matters for students' achievement gains: quasi-experimental evidence from elementary mathematics. *J. Educ. Psychol.* 94, 344–355. doi: 10.1037/0022-0663.94.2.344

Sung, Y.-T., Yang, J.-M., and Lee, H.-Y. (2017). The effects of Mobile-computer-supported collaborative learning: Meta-analysis and critical synthesis. *Rev. Educ. Res.* 87, 768–805. doi: 10.3102/0034654317704307

Tatto, M. T. (2021). Professionalism in teaching and the role of teacher education. *Eur. J. Teach. Educ.* 44, 20–44. doi: 10.1080/02619768.2020.1849130

van Laar, E., van Deursen, A. J., van Dijk, J. A., and de Haan, J. (2017). The relation between 21st-century skills and digital skills: a systematic literature review. *Comput. Hum. Behav.* 72, 577–588. doi: 10.1016/j.chb.2017.03.010

Vangrieken, K., Dochy, F., Raes, E., and Kyndt, E. (2015). Teacher collaboration: a systematic review. *Educ. Res. Rev.* 15, 17–40. doi: 10.1016/j.edurev.2015.04.002

Vogelsang, C., Finger, A., Laumann, D., and Thyssen, C. (2019). Vorerfahrungen, Einstellungen und motivationale Orientierungen als mögliche Einflussfaktoren auf den Einsatz digitaler Werkzeuge im naturwissenschaftlichen Unterricht [prior experience, attitudes and motivational orientations as possible influencing factors on the use of digital tools in science lessons]. *Zeitsch. Didak. Naturwissensch.* 25, 115–129. doi: 10.1007/s40573-019-00095-6

Vuorikari, R., and Brečko, B. N. (2013). How could teachers' professional collaboration in teacher networks be better studied as part of digital competence?

Vuorikari, R., Kluzer, S., and Punie, Y. (2022). Digcomp 2.2—the digital competence framework for citizens: with new examples of knowledge, skills and attitudes (EUR JRC128415). Europäische Kommission. Available online at: https://op.europa.eu/en/publication-detail/-/publication/50c53c01-abeb-11ec-83e1-01aa75ed71a1/language-en/format-PDF/source-280137285 (Accessed October 25, 2024)

Wigfield, A., and Eccles, J. S. (2000). Expectancy-value theory of achievement motivation. *Contemp. Educ. Psychol.* 25, 68–81. doi: 10.1006/ceps.1999.1015

Yeung, A. S., Tay, E. G., Hui, C., Lin, J., and Low, E.-L. (2014). Pre-service teachers' motivation in using digital technology. Australian. *J. Teach. Educ.* 39, 135–153. doi: 10.14221/ajte.2014v39n3.1

Zee, M., and Koomen, H. M. Y. (2016). Teacher self-efficacy and its effects on classroom processes, student academic adjustment, and teacher well-being. *Rev. Educ. Res.* 86, 981–1015. doi: 10.3102/0034654315626801