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Promoting pre- and in-service teachers' digital competence by using reverse mentoring

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Abstract The study investigated the effectiveness of reverse mentoring as an innovative instructional method to promote pre- and in-service teachers' digital competence. We conducted a quasi-experimental intervention study with 90 pre-service and 57 in-service teachers who took part in two-day online-workshops. The effectiveness of the reverse mentoring-intervention, where pre- and in-service teachers worked together in pairs to jointly develop ideas for the use of digital technology in the classroom, was compared to collaborative learning formats among peers in university seminars for pre-service teachers (control group 1) and professional development workshops for in-service teachers (control group 2). Technological-pedagogical knowledge (TPK), self-efficacy and positive beliefs about teaching with digital technology were investigated as outcomes. Pre- and in-service teachers in all groups gained in self-efficacy beliefs, whereby reverse mentoring was not more effective than the control conditions. TPK and positive beliefs about teaching with digital technology did not change over the course of the interventions. The results show that pre-service teachers can effectively act as mentors for in-service teachers to support their self-efficacy beliefs regarding the use of digital technology. However, we did not find evidence that reverse mentoring is more effective than peer learning among pre-service and in-service teachers to promote digital competence.

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Förderung digitaler Kompetenz von Lehramtsstudierenden und Lehrkräften durch Reverse Mentoring

Zusammenfassung Die Studie untersuchte die Wirksamkeit von Reverse Mentoring als innovative Lehrmethode zur Förderung digitaler Kompetenz bei Lehrkräften und Lehramtsstudierenden. Hierzu wurde eine quasi-experimentelle Interventionsstudie mit 90 Lehramtsstudierenden und 57 Lehrkräften durchgeführt, die an zweitägigen Online-Workshops teilnahmen. Die Wirksamkeit der Reverse-Mentoring-Intervention, bei der Lehramtsstudierende und Lehrkräfte in Tandems zusammenarbeiteten und gemeinsam Ideen zum Einsatz digitaler Medien im Unterricht zu entwickelten, wurde mit kooperativen Lernformaten nur mit Studierenden in Universitätsseminaren (Kontrollgruppe 1) und Fortbildungen nur mit Lehrkräften (Kontrollgruppe 2) verglichen. Als abhängige Variablen wurden technologisch-pädagogisches Wissen (TPK), Selbstwirksamkeit und positive Überzeugungen zum Unterrichten mit digitalen Medien untersucht. Die Selbstwirksamkeitsüberzeugungen von Lehramtsstudierenden und Lehrkräften verbesserte sich in allen Gruppen signifikant, die Reverse Mentoring-Intervention war jedoch nicht effektiver als die Kontrollbedingungen. TPK und positive Überzeugungen zum Unterrichten mit digitalen Medien änderten sich nicht im Verlauf der Interventionen. Die Ergebnisse zeigen, dass Lehramtsstudierende effektiv als Mentor*innen für Lehrkräfte fungieren können, um deren Selbstwirksamkeitsüberzeugungen zum Einsatz digitaler Medien zu verbessern. Unsere Daten zeigen jedoch keine Hinweise, dass Reverse Mentoring wirksamer ist als reguläre Peer-Learning-Formate, um digitale Kompetenz zu fördern.

Schlüsselwörter Lehrkräftebildung · Fort- und Weiterbildung · Digitale Kompetenz · Reverse Mentoring · Intervention

1 Introduction

As all aspects of life are becoming increasingly digital and since the widespread switch to remote instruction due to the COVID-19 pandemic, teachers face the challenge of providing high-quality instruction by integrating digital technologies into their teaching (Baier and Kunter 2020; Chai et al. 2013). Therefore, they need a high level of digital competence that comprises technology-related knowledge, self-efficacy and positive beliefs towards technology integration (Petko 2012; Seufert et al. 2021). However, results of a study by Hämäläinen et al. (2021) pooled across eleven European countries showed that especially older teaching professionals had weak digital skills, whereas the youngest teaching professionals believed that they were well prepared for using digital technologies in teaching.

In Germany, in-service teachers use technology less frequently in their teaching than teachers from other countries (Drossel et al. 2019). At the same time, German pre-service teachers are less likely to use digital technology when compared to students from other disciplines (Blume 2020). Thus, it seems necessary to enhance both pre- and in-service teachers' digital competence. However, empirical research is lacking on how to best prepare them for the use of digital technology in teaching (Lachner et al. 2021). Regarding pre-service teachers, different educational strategies like role model, collaboration, authentic experience and lesson planning practice have been described in the literature (Tondeur et al. 2012) and examined for pre-service teachers' digital competence development (e.g., Dooly and Sadler 2013; Lee and Lee 2014). Yet, different interventions have seldom been systematically compared, therefore no conclusions can be drawn at present as to which method of instruction is most effective (Lachner et al. 2021).

A similar picture emerges for in-service teachers' professional development on technology integration (Lawless and Pellegrino 2007). Although effective strategies concerning digital competence like sustained, active and reflective cooperative instructional design have repeatedly been proposed in professional development models (e.g., Darling-Hammond and Richardson 2009; Desimone 2009; Harris 2016), empirical evidence for their individual effectiveness is inconclusive or scarce (Harris 2016; Lawless and Pellegrino 2007; Opfer and Pedder 2011). Moreover, hardly any differential effects have been examined so far, such as interventions that could be particularly well-suited for teaching professionals with little prior experience in technology integration.

Few studies have focused on how both pre- and in-service teachers' digital competence can be enhanced simultaneously and how they may benefit each other (cf. Margerum-Leys and Marx 2002). Reverse mentoring, a unique form of mentoring where the traditional roles of a more experienced mentor and a less experienced mentee are switched (Zauchner-Studnicka 2017), has been proposed as an innovative strategy to support digital competence. Regarding teacher education, the more experienced in-service teachers learn from pre-service teachers about current trends in technology integration, whereas pre-service teachers benefit from the practical experience of the in-service teachers (Polly et al. 2010). To our knowledge, quantitative quasi-experimental evidence for the effectiveness of reverse mentoring in any field does not exist yet.

The present study therefore addresses the lack of research on the differential effectiveness of instructional strategies to improve digital competence and investigates the suggested added value of reverse mentoring compared to other collaborative interventions. Reverse mentoring presents a means of enhancing the digital competence of both groups simultaneously and therefore seems to be particularly economical.

1.1 Digital competence of pre- and in-service teachers

Pre- and in-service teachers' digital competence entails their *knowledge* about digital technology in teaching, their *self-efficacy*, and their positive/negative *beliefs* towards technology (Seufert et al. 2021). These aspects have been empirically investigated and shown to be important predictors of teachers' technology integration (Bos et al. 2014; Hämäläinen et al. 2021; Jin and Harp 2020; Petko 2012). They have also been the focus of intervention studies in pre-service teacher education and in-service teachers' professional development (e.g., Bos 2011; Kafyulilo et al. 2016; Lachner et al. 2021; Ning et al. 2022). The importance of teachers' knowledge about technology integration is theoretically motivated by the TPACK framework (Koehler and Mishra 2009). According to this, teachers must not only have generic knowledge about technology, but also knowledge about technology that interacts and is integrated with their knowledge about pedagogy and the content to be taught (Koehler and Mishra 2009). Technological pedagogical knowledge (TPK) entails knowledge about different (digital) technologies to enable teaching approaches and student learning without a specific reference to subject matter (e.g., computer-supported collaborative learning; Chai et al. 2013). Technological pedagogical content knowledge (TPCK) is knowledge of using different technologies to teach and facilitate students' knowledge creation of specific subject content (Chai et al. 2013). Both kinds of knowledge have emerged as particularly relevant aspects of teachers' knowledge about technology integration (Koehler and Mishra 2009; Lachner et al. 2019). Teacher beliefs and their self-efficacy regarding technology integration can theoretically be grounded in the "will, skill, tool model" (Knezek and Christensen 2016). Teachers' self-efficacy beliefs on technology integration have often been studied based on the conceptualizations of TPK and TPCK by self-report scales (e.g., Scherer et al. 2017). Furthermore, these constructs have often been supplemented by the study of teachers' positive and negative beliefs towards technology integration (e.g., Hämäläinen et al. 2021; Petko 2012) to more comprehensively describe teachers' digital competence.

German *in-service* teachers show gaps in these aspects of digital competence (Blume 2020). Furthermore, German *pre-service* teachers show less digital affinity than students of other disciplines (Schmid et al. 2017). Moreover, pre-service teachers usually lack longtime pedagogical and curriculum experience that could help to reflect the adequacy of using digital technology in practice (Meskill et al. 2006; Polly et al. 2010). However, in contrast to many (older) in-service teachers, they have been exposed to a systematic development of their digital competence in teacher education courses (Hämäläinen et al. 2021) that seek to transmit scientific, evidence-based knowledge (Blomberg et al. 2013). Given the lacks of German pre- and in-service teachers in their digital competence and the importance of this competence for effective technology integration (e.g., Petko 2012), it seems relevant to investigate interventions that systematically and effectively foster the digital competence of both groups.

1.2 Strategies to promote pre- and in-service teachers' digital competence

At present, most pre-service teachers are taught some kind of knowledge about digital technology integration in formal teacher education programs at university (Ning et al. 2022). In-service teachers usually acquire new knowledge, for example, knowledge about digital technology, via informal learning or formal professional development courses (Lawless and Pellegrino 2007). Many older in-service teachers, however, did not learn about technology integration during their initial teacher education, and consequently do not feel well-prepared for it (Hämäläinen et al. 2021). According to Darling-Hammond and Richardson (2009) and Desimone (2009), important strategies for effective teacher professional development are collaborative strategies that are job-embedded, active and reflective, focus on content, and are of sufficient duration. Specifically, in terms of in-service teachers' TPACK development, collaborative instructional design has been highlighted and is still widely used as a promising constructivist approach (Harris 2016; Koehler and Mishra 2005). The perceived expertise gap that exists between pre-service teachers and older in-service teachers in terms of digital competence (Hämäläinen et al. 2021) has rarely been used as an opportunity to foster the digital competence of both groups in a collaborative learning environment (cf. Margerum-Leys and Marx 2002; Meskill et al. 2006).

1.2.1 Reverse mentoring

Mentoring is characterized by a "stable dyadic relation between an experienced mentor and a less experienced mentee" (Ziegler 2009, p. 11). Reverse mentoring is a unique form of mentoring where these traditional roles are reversed between "one or more less experienced mentor/s providing specific expertise and one or more experienced mentee/s who want/s to gain this knowledge" (Zauchner-Studnicka 2017, p. 516). Contrary to traditional mentoring, reverse mentoring is characterized by a *shorter*, specific content-driven relationship (Clarke et al. 2019). It is considered to be an "effective strategy for mutual learning" (Valle et al. 2022, p. 65) about a specific topic and is based on reciprocity and the learning of both, the mentee and the mentor (Clarke et al. 2019). For reverse mentoring to be effective, mentors and mentees both need to contribute specific aspects of expertise in different areas (Augustiniene and Ciuciulkiene 2013; Clarke et al. 2019; Singer and Maher 2007). Theoretically, a positive mentee-mentor-relationship should be characterized by respect, patience, motivation, effective communication and professional feedback (Clarke et al. 2019).

Reverse mentoring was developed and firstly implemented in IT sectors, where younger employees supported older employees in using new technology (Clarke et al. 2019). In this context, reverse mentoring is used to promote cross-generational relationships between senior and junior employees and enhance technological knowledge (Valle et al. 2022). More experienced mentees are expected to learn "newest content knowledge or technical skills" (Augustiniene and Ciuciulkiene 2013, p. 75), while the junior mentors may benefit from gaining organizational knowledge, values endorsed in the workplace, and practical skills (Clarke et al. 2019). Reverse mentoring has not only been implemented in IT sectors but also in several other areas (e.g., business, medicine, education). In medical education, it has been described as a strategy to break down hierarchical structures and bring evidence-based up-to-date knowledge to the community (Clarke et al. 2019). The concept has also been explored in various educational contexts such as higher education, school education and teacher education and professional development (e.g., Polly et al. 2010; Singer and Maher 2007; Valle et al. 2022). In educational contexts, mentor and mentee are not solely defined by their age and cross-generational aspects, but by their seniority of expertise in the specific field (Augustiniene and Ciuciulkiene 2013). Importantly, only a few studies have explored reverse mentoring as a concept by which specifically in-service school teachers learn from pre-service teachers (e.g., Porras et al. 2018; Singer and Maher 2007; Valle et al. 2022).

1.2.2 Effectiveness of reverse mentoring

Reverse mentoring allows for an exchange of different types of expertise and knowledge is constructed both by the mentor and the mentee (Zauchner-Studnicka 2017). The assumed effectiveness of reverse mentoring can be motivated against the background of social and constructivist learning theories (Clarke et al. 2019; Zauchner-Studnicka 2017). Here, knowledge is actively constructed in the *zone of proximal development* (Vygotsky 1978) and interaction with more knowledgeable others. One theoretical expectation is that the younger mentors (pre-service teachers) benefit from explaining to and sharing knowledge with a usually more experienced person (in-service teacher). Explaining is generally associated with deeper understanding of the content (Bargh and Schul 1980; Fiorella and Mayer 2016). Furthermore, explaining to the mentee and perceiving oneself as an expert to a usually more competent partner can lead to an increase in self-efficacy beliefs and intrinsic motivation (Clarke et al. 2019; Deci and Ryan 2012). Pre-service teachers may experience feelings of empowerment, competence, and satisfaction (Clarke et al. 2019) and be willing to provide high-quality explanations of the content.

It is assumed that the more experienced mentees (in-service teachers) benefit from the "youthful energy" (Tobin 2004, p. 117) with whom the pre-service teachers share the current scientific knowledge about technology integration that they have just acquired in their university course (Clarke et al. 2019). Furthermore, research has shown that in-service teachers prefer trainers for professional development courses who are school teachers themselves and not, for example, researchers at universities (Schulze-Vorberg et al. 2021). In-service teachers may show higher acceptance and motivation to participate in an intervention like reverse mentoring, where pre-service teachers, who will be school teachers, act as mentors.

Although reverse mentoring has repeatedly been highlighted as an effective strategy to increase (technological) knowledge and skills, empirical evidence on its effectiveness is limited (Clarke et al. 2019; Valle et al. 2022). Very few empirical studies have been conducted on reverse mentoring (or very similar concepts), and those that do exist are usually small case studies not including comparison or control groups.

In the educational area, Valle et al. (2022) implemented reverse mentoring in elementary schools with five pairs of pre- and in-service teachers. The authors conclude that reverse mentoring can help transform in-service teachers' beliefs about teaching English. Pre-service teachers were perceived as a "credible source of knowledge and as possessing expertise" (p. 74) by the in-service teachers. In a study by Meskill et al. (2006), six pre- and four in-service teachers worked in small groups in a long-term mentoring relationship over a year and developed classroom activities and materials including technology. Classroom observations and interview data showed that pre-service teachers found it very helpful to have support from in-service teachers regarding "everyday logistics of the classroom" (Meskill et al. 2006, p. 289). Further, pre- and in-service teachers shared ideas and developed "synergistic visions about technology use and integration" (Meskill et al. 2006, p. 291). Results from interviews and observations of three pre- and in-service teacher pairs in a study by Margerum-Leys and Marx (2002) also showed that all participants gained knowledge on technology use in the classroom, and in-service teachers perceived the cooperation with pre-service teachers to be crucial for their professional development. Singer and Maher (2007) report similar results from two pre- and in-service teacher pairs teaching science classes and showed that pre-service teachers were able to help their in-service teachers mentees use technological innovations in the classroom.

The results indicate that reverse mentoring is promising for promoting knowledge and beliefs in educational contexts. However, sample sizes in the existing studies are very small, and there are no quantitative studies including control groups. Thus, it is not clear whether participants do indeed benefit from the reversed roles that are associated with higher motivation, and potentially more in-depth explanations, or whether they generally benefit from the collaborative work and exchange that is not unique to reverse mentoring.

2 The present study

The goal of the present study was to examine the effectiveness of reverse mentoring to promote digital competence (i.e., knowledge, self-efficacy, positive beliefs) of both pre- and in-service teachers. Collaborative methods such as peer learning have shown to be effective in supporting academic, motivational, and attitudinal outcomes in different educational settings (e.g. Ginsburg-Block et al. 2006). Therefore, we assume that participants will expand their knowledge by learning about the benefits of teaching with digital technology and by using specific digital tools. This should also increase their self-efficacy to use digital tools for teaching and form positive beliefs that digital technology can be beneficial for teaching and learning.

In reverse mentoring, the traditional mentoring structures are turned around. In the present study this means that pre-service teachers share their scientific and conceptual TPK acquired in their teacher education course with experienced in-service teachers; in-service teachers, in turn, share their practical classroom expertise with pre-service teachers to jointly develop ideas for the effective use of digital technology in the classroom. The reciprocity of the relationship is significant. It is assumed that both groups will benefit from the relationship because both groups fulfil a specific expert role. The reverse mentoring intervention includes specific (collaborative) elements (e.g., explaining to a more competent person; receiving information from an engaged and motivated younger mentor; uniting pre- and in-service teachers) which is expected to be particularly effective to promote knowledge, self-efficacy, and positive beliefs.

In contrast to previous studies, the effectiveness of reverse mentoring will be investigated in a quasi-experimental pre-post design including strong comparison groups. In the comparison groups, collaborative elements will also be included. However, pre- and in-service teachers will not collaborate and thus not be exposed to the specific elements of reverse mentoring. We aim to explore the following research question and hypotheses:

Is reverse mentoring more effective in promoting pre- and in-service teachers' digital competence than traditional collaborative learning interventions?

(H1) We assume that reverse mentoring is more effective in promoting pre-service teachers' (H1a) TPK, (H1b) self-efficacy in teaching with digital technology, and (H1c) positive beliefs about digital technology in the classroom than traditional collaborative learning as practiced in university seminars for pre-service teachers.

(H2) Equally, we assume that reverse mentoring is more effective in promoting in-service teachers' (H2a) TPK, (H2b) self-efficacy in teaching with digital technology, and (H2c) positive beliefs about digital technology in the classroom than traditional collaborative learning practiced in professional development workshops for in-service teachers.

3 Method

3.1 Design and procedure

We conducted a quasi-experimental intervention study and compared changes in digital competence in reverse mentoring (intervention group; IG) with traditional collaborative learning among pre-service teachers in university seminars (control group 1; CG1) and among in-service teachers in professional development courses (control group 2; CG2). The content of the intervention courses was equal for all groups and focused on TPK, i.e. approaches for teaching with digital technology that can be applied equally well across different subjects. First, functions and potentials of digital technology and how digital technology can support good teaching were discussed. Next, various digital tools for different didactic scenarios were introduced, such as collaborative learning, individualization and activation. The content of the courses was aligned to items in the TPK knowledge test that was used to assess the effectiveness of the intervention. To explore whether the method of reverse mentoring seems feasible and gainful, telephone interviews with teachers ($N=5$) had been conducted in advance which showed that the in-service teachers considered the method to be suitable to help with technology integration in the classroom.

The intervention design is presented in Table 1. Pre-service teachers in the reverse mentoring condition (IG) first took part in five 90-minute online lessons spread across 20 weeks, in which knowledge about digital technology was introduced and the mentioned topics were discussed. After this introductory phase, where pre-service teachers acquired specific expert knowledge, they were each paired with an in-service teacher and both took part in a two-day online workshop with reverse mentoring together. A lecturer moderated and structured the reverse mentoring phases with short phases of introduction and reflections in plenary sessions. On the first day, pre-service teachers shared their knowledge about digital technology with their respective in-service teacher. They explained functions and benefits of digital tech-

Table 1 Intervention design

Group	Intervention group	Control group 1	Control group 2
Participants	Pre- and in-service teachers	Pre-service teachers	In-service teachers
Format	Reverse mentoring course	University seminar	Professional development workshop
Procedure	1) Five 90-minute online lessons spread across 20 weeks (only for pre-service teachers)	1) Five 90-minute online lessons spread over 20 weeks	–
	2) Two-day online workshop	2) Two-day online workshop	1) Two-day online workshop

nology in teaching, introduced a variety of digital tools, and practiced using the tools together. In-service teachers contributed their practical teaching experience and the pairs jointly developed ideas on how to use the tools in teaching. The second day, pre- and in-service teachers developed a lesson plan together that integrated digital technology and applied their newly acquired knowledge to a practical situation.

To assess whether core elements of reverse mentoring were implemented as intended in the pairs, self-developed items on implementation fidelity on a six-point Likert-type scale (1 = strongly disagree – 6 = strongly agree) were included in the questionnaires for the IGs. In-service teachers on average agreed that pre-service teachers explained content to them ($M = 4.69$; $SD = 1.09$) and presented ($M = 4.85$; $SD = 1.08$) and explained ($M = 4.73$; $SD = 1.40$) various digital tools. Pre-service teachers also on average agreed that in-service teachers explained content ($M = 4.92$; $SD = 1.32$) and supported them in designing lesson plans ($M = 5.35$; $SD = 1.06$).

In the traditional university seminars (CG1), pre-service teachers also took part in five 90-minute online lessons spread across 20 weeks and in a two-day online-workshop. They developed a lesson plan with digital technology in pairs, together with another pre-service teacher (peer-learning). In-service teachers in the professional development workshops (CG2) took part in a two-day online workshop. The first day, a lecturer presented the contents of the course, and participants practiced using the digital tools. The second day, in-service teachers developed a lesson plan with digital technology collaboratively working in pairs of in-service teachers.

3.2 Sample

In total, 147 pre- and in-service teachers participated in the study and completed at least one of the evaluation surveys before and after the two-day workshop. 57 pre-service teachers took part in traditional university seminars (CG1) and 24 teachers took part in professional development courses (CG2). The reverse mentoring condition (IG) was carried out with 33 pre-service teachers and 33 in-service teachers. The descriptive information of the groups can be found in Table 2. Participation in the study was voluntary for all participants. The courses for pre-service teachers in the CG1 took place in 2021 and 2022 as part of their study program at a German University. The IG courses for pre- and in-service teachers were carried out in 2022 and 2023. Pre-service teachers also registered for the courses as part of their

Table 2 Demographic data for the intervention and control groups

Variable	Pre-service teachers				In-service teachers			
	IG		CG1		IG		CG2	
	n (%)	*M (SD)*	*n (%)*	*M (SD)*	*n (%)*	*M (SD)*	*n (%)*	*M (SD)*
Gender								
Female	26 (78.8)	–	27 (47.3)	–	25 (75.8)	–	17 (70.8)	–
Male	7 (21.2)	–	19 (33.3)	–	8 (24.2)	–	7 (29.2)	–
Diverse	0 (0.0)	–	1 (0.2)	–	0 (0.0)	–	0 (0.0)	–
Missing	0 (0.0)	–	10 (17.5)	–	0 (0.0)	–	0 (0.0)	–
Age (years)	–	24.21 (5.31)	–	25.88 (6.94)	–	37.33 (7.86)	–	38.95 (9.02)

IG intervention group (reverse mentoring), *CG* control group

study program. In-service teachers from all parts of Germany could participate in the reverse mentoring courses and were recruited through advertising in schools and online newsletters. Also, pre-service teachers recruited in-service teachers via personal contacts. The description of the courses stated that pre- and in-service teachers would be working together in pairs via reverse mentoring. The pairs in the IG were matched according to their subjects and school form. The CG2 workshops for in-service teachers were held in 2022 and in-service teachers were also recruited via schools and online newsletters.

Pre-service teachers in the IG and CG1 did not differ in terms of age ($t(75)=1.11$, $p=0.27$, $d=0.26$) and gender ($\chi^2(2)=4.24$, $p=0.12$, $\varphi=0.23$). Equally, in-service teachers in the IG and CG2 did not differ in terms of age ($t(50)=0.69$, $p=0.49$, $d=0.19$), and gender ($\chi^2(1)=0.17$, $p=0.68$, $\varphi=0.06$).

3.3 Measures

The evaluation surveys were conducted as online questionnaires at the beginning and end of the two-day workshops.

3.3.1 Technological-pedagogical knowledge

To assess pre- and in-service teachers' TPK, a short version of the TPK test developed by Baier and Kunter (2020) was used. The short version consisted of seven items with free-response format. A sample item is: "You as a teacher would like to adapt your instruction to the individual learning needs of your students. In what ways may digital media help you to achieve this aim?" The answers were coded based on a deductively developed and inductively revised coding scheme (see supplementary material and Baier and Kunter 2020). A participant's score on an item is the sum of conceptually distinct correct answers on that item (see Baier and Kunter 2020). The maximum number of points varies between items. In the short version, a maximum of 63.5 points can be scored. 16% of the answers were coded by two trained raters. Interrater reliabilities were $\kappa_{item2} = 0.95$, $\kappa_{item4} = 0.88$, $\kappa_{item5} = 0.96$, $\kappa_{item6} = 0.97$, $\kappa_{item10} = 0.96$, $\kappa_{item15} = 0.96$, $\kappa_{item16} = 0.97$. The rest of the answers were coded by one of the raters. The test showed acceptable internal consistency for both pre-service (pretest $\alpha = 0.65$; posttest $\alpha = 0.71$) and in-service teachers (pretest $\alpha = 0.63$; posttest $\alpha = 0.73$).

3.3.2 Self-efficacy beliefs in teaching with digital technology

Self-efficacy beliefs in teaching with digital technology were assessed using a six-point Likert-type scale (1 = totally disagree – 6 = totally agree) with nine items by Schmidt et al. (2009). A sample items is: "I can select digital technology that enriches the instructional approaches of a lesson." The scale showed good reliability for pre- and in-service teachers at both time-points (pre-service teachers: pretest $\alpha = 0.85$; posttest $\alpha = 0.89$; in-service teachers: pretest $\alpha = 0.87$; posttest $\alpha = 0.86$).

3.3.3 Positive beliefs about digital technology in the classroom

Positive beliefs about teaching with digital technology were assessed with eight items on a four-point Likert-type scale (1 = totally disagree – 4 = totally agree) by Jung and Carstens (2015). Positive beliefs thereby refer to digital technologies being considered useful and positively influencing students' learning processes. A sample item is: "The use of digital media at school improves students' academic achievement". The scale showed acceptable to good reliability for pre- and in-service teachers at both time-points (pre-service teachers: pretest $\alpha = 0.74$; posttest $\alpha = 0.68$; in-service teachers: pretest $\alpha = 0.74$; posttest $\alpha = 0.80$).

3.4 Statistical analyses

To evaluate the effectiveness of reverse mentoring, we conducted separate repeated measure ANOVAs for pre- and in-service teachers. Time (pretest, posttest) was modeled as a within-subject factor and condition (intervention vs. control group) as between-subject factor for the investigated constructs. In the control groups, 37 pre-service teachers and 18 in-service teachers completed both surveys before and after the workshops, and their data can therefore be included in the analyses of treatment effects. In the reverse mentoring condition, 25 pre-service teachers and 24 in-service teachers completed both surveys before and after the two-day workshops, and can be included in the calculations. Within-group homoscedasticity was given for all measures but not all measures were normally distributed in all groups, due to the small sample sizes. Still, ANOVAs are considered to be robust against violations of the normality assumption (Blanca et al. 2017). Effect sizes are reported for partial η^2, where 0.01 indicates a small, 0.06 a medium, and 0.14 a large effect (Cohen 1988). To check the robustness of the results, non-parametric analyses were performed and the same results regarding statistical significance were obtained.

4 Results

Table 3 displays the descriptive statistics for the analyzed measures. In the present study, participants of all groups and time points scored between 0 and 22 points in the TPK test. First, we analyzed comparability pre- and in-service teachers' pretest scores. Pre-service teachers in the IG and CG1 did not differ significantly in their pretest scores for TPK ($t(73)=1.81$, $p=0.07$, $d=0.43$), self-efficacy ($t(76)=0.47$, $p=0.64$, $d=0.11$), and positive beliefs about digital technology ($t(76)=–0.30$, $p=0.76$, $d=0.07$). Equally, in-service teachers in the IG and CG2 did not differ in their pretest scores for TPK ($t(50)=–0.96$, $p=0.34$, $d=–0.27$), self-efficacy ($t(50)=–0.98$, $p=0.33$, $d=–0.27$) and positive beliefs about digital technology ($t(50)=0.73$, $p=0.47$, $d=0.21$). Further, pre- and in-service teachers in the IG did not differ significantly in their pretests scores for TPK ($t(58)=–1.86$, $p=0.07$, $d=–0.48$), self-efficacy beliefs ($t(58)=0.60$, $p=0.55$, $d=–0.16$), and positive beliefs about digital technology ($t(58)=1.22$, $p=0.23$, $d=0.31$).

Following our research question, we analyzed the hypothesized effects of reverse mentoring by calculating repeated-measures ANOVAs. We report the results separately for pre- and in-service teachers.

Pre-service teachers' TPK did not improve significantly in either group. We found no significant main effect for time ($F(1,59)=0.23$, $p=0.64$, $\eta^2=0.01$). Equally, no significant group effect ($F(1,59)=1.74$, $p=0.19$, $\eta^2=0.03$) or interaction effect ($F(1,59)=1.01$, $p=0.32$, $\eta^2=0.02$) was found. For pre-service teachers' self-efficacy beliefs, we found a significant main effect for time with a large effect size ($F(1,58)=54.57$, $p<0.01$, $\eta^2=0.49$), indicating that pre-service teachers' self-efficacy beliefs improved in both groups over the course of the two-day workshops. However, no significant group effect ($F(1,58)=0.81$, $p=0.37$, $\eta^2=0.01$) or interaction effect ($F(1,58)=0.23$, $p=0.64$, $\eta^2=0.004$) was found. Positive beliefs about digital technology also did not improve over time in either group of pre-service teachers ($F(1,59)=3.64$, $p=0.06$, $\eta^2=0.06$). Equally, no significant group effect ($F(1,59)=0.35$, $p=0.56$, $d=0.01$) or interaction effect ($F(1,59)=0.80$, $p=0.38$, $\eta^2=0.01$) emerged. Our hypotheses that reverse mentoring is more effective than

Table 3 Descriptive statistics for pre-service and in-service teachers

Time	Measure	Pre-service teachers				In-service teachers			
		IG		CG1		IG		CG2	
		n	*M (SD)*	*n*	*M (SD)*	*n*	*M (SD)*	*n*	*M (SD)*
Pre	TPK	25	8.12 (4.04)	36	10.00 (4.48)	24	9.96 (4.43)	16	8.91 (3.58)
Post	TPK	25	8.86 (4.37)	36	9.74 (4.71)	24	9.04 (5.71)	16	8.00 (3.86)
Pre	Self-efficacy beliefs	24	4.38 (0.51)	36	4.47 (0.56)	23	4.21 (0.83)	18	4.20 (0.89)
Post	Self-efficacy beliefs	24	4.77 (0.56)	36	4.91 (0.54)	23	4.78 (0.70)	18	4.60 (0.80)
Pre	Positive beliefs	24	3.00 (0.32)	37	3.02 (0.42)	23	2.93 (0.39)	18	2.99 (0.46)
Post	Positive beliefs	24	3.03 (0.29)	37	3.12 (0.35)	23	2.99 (0.44)	18	3.00 (0.42)

Descriptive statistics are depicted only for those who participated in both the pre- and posttest measure
IG intervention group (reverse mentoring), *CG* control group

traditional collaborative learning among pre-service teachers in university seminars to promote TPK (H1a), self-efficacy beliefs (H1b) and positive beliefs about digital technology (H1c) could therefore not be confirmed.

A similar picture emerged for the in-service teachers. In-service teachers' TPK did not improve significantly over the course of the two-day workshops in either group, and no significant main effect for time was found ($F(1,38) = 2.07$, $p = 0.16$, $\eta^2 = 0.05$). Equally, no significant group effect ($F(1,38) = 0.63$, $p = 0.44$, $\eta^2 = 0.02$) or interaction effect ($F(1,38) = 0.00$, $p = 0.99$, $\eta^2 = 0.00$) was found. For self-efficacy beliefs of in-service teachers, the analyses revealed a significant main effect for time with a large effect size ($F(1,39) = 21.93$, $p < 0.01$, $\eta^2 = 0.36$). However, no significant group effect ($F(1,39) = 0.17$, $p = 0.69$, $\eta^2 = 0.004$) or interaction effect ($F(1,39) = 0.72$, $p = 0.40$, $\eta^2 = 0.02$) emerged. Positive beliefs about digital technology did not improve over time in either group of in-service teachers ($F(1,39) = 0.28$, $p = 0.60$, $\eta^2 = 0.01$). Equally, no significant group effect ($F(1,39) = 0.10$, $p = 0.75$, $\eta^2 = 0.003$) or interaction effect ($F(1,39) = 0.09$, $p = 0.76$, $\eta^2 = 0.002$) was found. Our hypotheses that reverse mentoring is more effective in promoting TPK (H2a), self-efficacy beliefs (H2b) and positive beliefs about digital technology (H2c) than traditional collaborative learning among in-service teachers in professional development workshops could therefore not be confirmed.

5 Discussion

5.1 Summary and interpretation of the findings

We investigated the effectiveness of reverse mentoring as compared to more traditional collaborative learning formats for pre-service and in-service-teachers. To our knowledge, this is the first quasi-experimental study on reverse mentoring of pre- and in-service teachers with quantitative pre-post testing. We used strong comparison groups to isolate the specific effects of reverse mentoring.

A key finding of the present study is that reverse mentoring was *not more effective* in increasing pre- and in-service teachers' self-efficacy beliefs concerning technology integration than the other interventions that also included collaborative elements, but not the reversed mentoring relationship. The study therefore shows that the high hopes and positive reports from qualitative research based on small sample sizes without comparison groups concerning reverse mentoring (e.g., Porras et al. 2018; Singer and Maher 2007; Valle et al. 2022) should be taken with a grain of salt. Reverse mentoring is one concept among others that is effective for the increase of short-term self-efficacy. Our data do not provide evidence that this instructional strategy is *more* effective than other collaborative strategies, at least when technology-related self-efficacy as a short-term outcome is considered.

However, the findings of the present study also suggest that pre-service teachers are not *less* successful in helping in-service teachers increase their self-efficacy than highly-qualified trainers from university. Thus, pre-service teachers are able to fill the role of a competent mentor.

Another important finding of the present study is that neither of the interventions effectively increased pre- or in-service teachers' TPK and positive beliefs towards digital technology. These findings could be explained by the fact that the interventions were very short and were conducted completely online (due to the COVID-19 pandemic). Ning et al. (2022) showed in their meta-analysis that blended teaching was more effective than purely online teaching. Nevertheless, our findings are in line with research on teacher professional development that is often unable to show that individual quality aspects of teacher development like collaboration or reflection predict teacher learning (Opfer and Pedder 2011).

From a methodological perspective, the TPK test used in the present study may not have captured the aspects of knowledge that developed during the intervention. For example, the participants may rather have developed knowledge that is represented in the specific application of digital technology in subject-related situations. Other instruments may be better suited to depict the development of teachers' knowledge, for example, the quality of lesson plans (Harris et al. 2010) could be examined to infer participants' knowledge gain from reverse mentoring.

5.2 Limitations of the study

Although the study had a strong research design (quasi-experimental with strong comparison groups, pre-post measures) as compared to other studies in the field, methodological aspects could still be optimized and this might be a reason why only few effects emerged. One methodological limitation is the short duration of the intervention. Research has shown that interventions need a certain length of time to effectively build knowledge (Ning et al. 2022). Also, there was no follow-up test. Changes in beliefs need time for reflection in everyday life, which the participants in our study did not have as the posttest was conducted immediately after the intervention. Further, implementation quality of specific elements that are distinctive to reverse mentoring are crucial for the effectiveness of the method. We did assess self-reported adherence to specific core elements of reverse mentoring, but the validity of these self-reports may be limited due to social desirability (e.g. Dusenbury et al. 2005). Future research should also include objective measures (e.g., observations) to gain detailed insights into implementation quality.

Also, the assumption of competence differences between mentee and mentor in reverse mentoring was not given. Pre-service teachers in our sample did not show higher TPK or more positive beliefs about digital technology than in-service teachers in the pretest. The pre-service teachers had acquired substantial TPK through their university course, but they did not have more knowledge at the beginning of the two-day online workshop than the in-service teachers. Consequently, they could not provide many new insights to the in-service teachers, which already had a fair amount of TPK prior to the intervention. Although the pretest differences between pre- and in-service teachers in the IG were not significant, the effect size indicated a close to medium effect, suggesting that in-service teachers might even have displayed higher TPK than pre-service teachers. This might have contributed to the lack of effectiveness in terms of knowledge gain. According to the assumptions of effectiveness in reverse mentoring, we would have needed teachers with low TPK, low self-efficacy and more negative beliefs than pre-service teachers. Such a target group could more likely be identified among teachers in the age group (50 years or older) that seems to highly struggle with digital technology integration (Hämäläinen et al. 2021). Thus, the present study could not investigate whether reverse mentoring is an effective strategy for these teachers. This is unfortunate as reverse mentoring has explicitly been proposed as a valuable concept for cross-generational learning between the young and the old (Clarke et al. 2019; Valle et al. 2022). Since teachers voluntarily signed up for this training, it seems that more competent teachers participated in this format. This is in line with Schulze-Vorberg et al. (2021) who showed that predominately motivated and already technology-competent teachers voluntarily attended professional development courses on digital technology.

In addition, due to the pandemic situation and the associated contact restrictions, our intervention could only take place online, which had not been planned initially. Positive interactions and the establishment of a sustainable mentoring relationship is presumably much more difficult online, due to the lack of informal contact opportunities (Meyer et al. 2022).

5.3 Implications

The present study examined theoretical assumptions regarding the effectiveness of reverse mentoring. Prior research was mainly qualitative, and our present study is one of the first studies ever to investigate the effectiveness of reverse mentoring quantitatively including comparison groups. The results showed that apparently not the specific reversal of roles leads to positive effects on self-efficacy but rather collaboration in general may be effective (Harris 2016). However, further research should investigate these mechanisms with larger sample sizes. In the following, we derive an agenda for future research to further explore the reverse mentoring method. This may also provide helpful guidance for studies that seek to investigate the effectiveness of other instructional strategies. We also provide practical implications.

Target variables of the intervention Investigating other outcomes of reverse mentoring than those examined here could be promising. As the in-service teachers contribute their practical teaching experience, the quality of lesson plans and increase of pre-service teachers' practical knowledge could be examined. Since only the first half of the intervention was related to knowledge building, and the other half was about the application of this knowledge in a practical context, an evaluation instrument should do justice to this application-related knowledge. Also, the development of professional mentoring skills in pre-service teachers seems to be a relevant outcome (Clarke et al. 2019) that was not examined in our study. On the one hand, this includes the didactic success of the pre-service teachers in conveying the knowledge content to the teachers. On the other hand, this involves the motivational orientations, enthusiasm, and self-efficacy of pre-service teachers to take on the mentoring role for this topic. To examine these outcomes and mechanisms of action of reverse mentoring in greater depth, mixed-methods approaches with observations and interviews could be beneficial.

Preparation for mentoring role Further research could also focus on the processes and mechanisms of theoretically effective reverse mentoring, that is, the quality of explanations by the pre-service teachers, their level of motivation, and their experience of competence (Deci and Ryan 2012). Also, future research should more strongly consider the challenges associated with reverse mentoring that may also explain the lack of effects in the present study. Such challenges could lie in establishing a positive mentor-mentee relationship characterized by patience, motivation, effective communication and feedback (Clarke et al. 2019).

Recruitment strategy and target group of teachers Reverse mentoring should in particular be effective for teachers with little prior experience in using technology in the classroom. However, the recruitment of less experienced in-service teachers is challenging. Good concepts are needed to make participation in further training with reverse mentoring attractive for teachers. Teachers should be made aware of this professional development training through channels that do not yet require digital literacy and the target group of less experienced teachers should be addressed very explicitly. Ideally, these teachers could be filtered out in an assessment and assigned to reverse mentoring.

Working out the advantages of the reverse mentoring relationship Our results revealed that pre-service teachers generally seem to be capable of taking on the role of a mentor or trainer and can therefore be further integrated into the professional development of in-service teachers. Thus, the concept could be further tested as a tool to bring pre- and in-service teachers together and to reduce existing hierarchies in teacher education. It could help to appreciate pre-service teachers as equitable partners that can contribute up-to-date scientific knowledge to the field. In particular, the practical induction phase may benefit from this exchange at eye level and give beginning teachers the chance to share their specific expert knowledge (Singer and Maher 2007). More generally, our results show that collaboration in the teaching profession can be achieved across different phases of teacher education and training via reverse mentoring. Thinking further, reverse mentoring could be considered and innovative approach to expand so-called professional learning communities (Darling-Hammond and Richardson 2009) across different phases of teacher education. The practical induction phase could be a starting point for the creation of such mixed professional learning communities.

In light of the research situation on reverse mentoring and the results of our study, it is apparent that there are still many unanswered questions to conclusively evaluate the effectiveness of reverse mentoring. This agenda provides ideas to further investigate this method for promoting digital competence among pre- and in-service teachers. Only if future research succeeds in showing the increased effectiveness of reverse mentoring on outcomes such as knowledge and beliefs can it be considered a more fruitful method than similar approaches to improve digital competence economically.

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