



Teachers' trajectories of technology integration during participation in an online professional development program

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Received: 18 May 2023 / Revised: 7 February 2024 / Accepted: 23 February 2024 / Published online: 21 May 2024
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Abstract Technology-related professional development (PD) is a crucial strategy to prepare and encourage teachers to integrate technology into their teaching in a high-quality way. During teachers' participation in technology-related PD, change processes occur from a current to a desired status of technology-enhanced teaching (TET). A higher probability of disruption of TET can be assumed during these change processes. However, previous research on PD is mainly based on cross-sectional data that does not provide insight into such change processes (especially during PD participation). In this study, we examined teachers' trajectories closely during their participation in a 3-month technology-related online PD (OPD). We conducted a concurrent explanatory mixed-methods approach to analyze longitudinal data from the first four weeks of the OPD, focusing on 23 teachers who completed weekly reflection diaries. Findings from a multilevel framework revealed that most of the variances in the development of teachers' technology integration (i.e., frequency and quality) and motivation to use technology for teaching (i.e., self-efficacy and utility value) was due to contextual factors. Using linear mixed-effects models, we found a statistically significant decrease in teachers' quality of TET over time. Analyses of reflections on TET of extreme cases allowed us to identify possible relevant contextual characteristics related to smoother TET: 1) the use of one generic

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technology across lessons and 2) the use of ready-to-use domain-specific technology. Implications for practice are discussed, such as attention to unintended side effects of teachers' TET during instructional phases of technology-related OPD.

Keywords Online teacher professional development · Technology-enhanced teaching · Mixed-method · Reflection diary

Die Entwicklung der Technologieintegration von Lehrkräften während der Teilnahme an einer Onlinefortbildung

Zusammenfassung Technologiebezogene Fortbildungen (PD) sind eine bedeutende Strategie, um Lehrkräfte darauf vorzubereiten und zu ermutigen, Technologie in ihren Unterricht lernwirksam zu integrieren. Während der Teilnahme von Lehrkräften an technologiebezogenen PD finden Veränderungsprozesse von einem aktuellen zu einem gewünschten Status technologiegestützten Unterrichts (TET) statt. Während dieser Veränderungsprozesse kann eine höhere Wahrscheinlichkeit für eine Disruption des TET angenommen werden. Die bisherige Forschung zu Fortbildungen basiert jedoch hauptsächlich auf Querschnittsdaten, die keinen Einblick in solche Veränderungsprozesse – insbesondere während der Teilnahme an Fortbildungen – geben. In dieser Studie haben wir Lehrkräfte während ihrer Teilnahme an einer 3-monatigen technologiebezogenen Onlinefortbildung (OPD) eng begleitet. Wir nutzten einen erklärenden Mixed-Methods-Ansatz zur Auswertung von Längsschnittdaten von 23 Lehrkräften, die wöchentliche Lehrertagebücher anfertigten. Die Ergebnisse eines Mehrebenenmodells zeigten, dass die meiste Varianz in der Entwicklung der Technologieintegration von Lehrkräften (d. h. Häufigkeit und Reibungslosigkeit) und ihrer Motivation für den Einsatz von Technologie im Unterricht (d. h. Selbstwirksamkeit, Nutzenswahrnehmung) in erster Linie vom Kontext abhängen. Unter Verwendung von Modellen mit linearen gemischten Effekten fanden wir einen signifikanten Rückgang des reibungslosen Einsatzes von Technologie. Die Analyse der Reflexionen von Extremfällen über TET ermöglichte es uns, potenziell relevante kontextbezogene Merkmale zu identifizieren: 1) die Verwendung einer generischen Technologie im gesamten Unterricht und 2) die Verwendung einsatzbereiter domänenspezifischer Technologie. Es werden Implikationen für die Praxis erörtert, wie z. B. die Beachtung unbeabsichtigter Nebeneffekte bei der Integration von Technologie in den Unterricht in den Einstiegsphasen von technologiebezogenen Onlinefortbildungen.

Schlüsselwörter Online-Lehrerfortbildung · Technologiegestützter Unterricht · Mixed Methods · Reibungslosigkeit · Veränderungsmodell

The digital transformation requires teachers to deliberately integrate technology into their teaching to prepare students for a digitally shaped future. At the same time, technology integration has the potential to contribute to instructional quality and improve students' learning (Fraillon et al. 2019; Scheiter 2021). Despite these

technological promises for teaching and learning, empirical research showed that teachers seldom integrate technology, and when they do, it is only to substitute prior teaching practices without exploiting the full potential of technology for teaching (Backfisch et al. 2020; Fütterer et al. 2023a). Therefore, it is argued that technology-related professional development (PD) could support teachers to adopt technology in the classroom effectively and support students' learning (Fütterer et al. 2023b). Many providers of technology-related PD focused on introducing new technology or approaches to using technology for teaching. Introducing new technology implies that teachers are confronted with new knowledge and changes in workflows of technology-enhanced teaching (TET). Whereas theoretical models have hypothesized the effects of PD and in particular online PD (OPD)¹ on the teacher, classroom, and student levels (Darling-Hammond et al. 2017; Desimone 2009; Quinn et al. 2019) and research has focused on studying these effects, insights into effects on individual teachers and their development during a PD/OPD (e.g., how individual teachers adopt new information in their professional practice) are scarce. Regarding technology-related PD/OPD, most studies used cross-sectional or simple pre-posttest designs to investigate the effectiveness of PD/OPD at a specific time point. They thus only portrayed a snapshot instead of developments of technology integration. Specifically, there is a lack of longitudinal studies in which teachers' trajectories are closely examined (i.e., multiple times) regarding their TET to fully understand their technology integration and motivation during a PD/OPD.

In the theory section, we first delve into high-quality technology integration during teaching, focusing on the pivotal role of teacher competencies and PD/OPD. Following this, our study aims to elucidate intraindividual differences in technology integration and motivation for technology use among teachers undergoing technology-related PD/OPD, focusing on individual entry requirements. Employing an experience-sampling approach (e.g., Backfisch et al. 2021; Endedijk et al. 2014) through a weekly teacher diary during a 3-month OPD program involving 23 teachers, we analyze developmental trajectories during the first four weeks of the OPD intervention and pre-conditions of technology integration. Findings of a mixed-methods approach elucidate these trajectories. Finally, we address the study's inherent limitations, which serve as valuable starting points for future research.

1 Theoretical background

1.1 Technology integration during teaching with a focus on classroom management

In educational contexts, technology integration describes teachers' technology use, such as the use of hardware (e.g., mobile technology, tablets, see Beauchamp et al. 2015) or software applications (e.g., tools, see Krauskopf et al. 2012) for teaching (e.g., Backfisch et al. 2021; Fütterer et al. 2022; Dukuzumuremyi and Siklander

¹ In the following, we will use "PD" to refer to traditional (i.e., face-to-face PD), "OPD" to refer to online PD, and "PD/OPD" if we refer to both "PD" and "OPD".

2018; Paratore et al. 2016). Technology integration can be differentiated regarding frequency and quality (Fütterer et al. 2022).

With regard to *frequency*, technology integration refers to how often a particular technology is used for teaching (Fraillon et al. 2014, 2020). Such frequency assessments measure the general level of technology saturation at schools (Backfisch et al. 2021; Fütterer et al. 2022).

The *quality* of technology integration can be conceptualized by adapting indicators of generic teaching quality (Backfisch et al. 2021; Fütterer et al. 2022, 2023a). Teaching quality refers to task-specific (i.e., cognitive activation and student support) and task-general teaching practices (i.e., classroom management; Klieme et al. 2009; Praetorius et al. 2018; see also Seidel and Shavelson 2007; Pianta and Hamre 2009). *Cognitive activation* describes practices that enhance students' cognitive engagement with the learning content during teaching (Fauth and Leuders 2018; Fütterer et al. 2022, 2023a), for instance, by providing students with challenging tasks, exploring concepts, and activating prior knowledge. Such practices should contribute to deep processing of the learning content and foster students' subject-specific understanding (Fauth et al. 2014; Fütterer et al. 2022). *Student support* describes practices that support students during learning (Kunter et al. 2013; Praetorius et al. 2018) by utilizing student-centered and adaptive teaching activities (Corno 2008), such as monitoring learning processes or giving adaptive feedback to students (Klieme et al. 2009; van de Pol et al. 2015).

Classroom management comprises task-general teaching practices that aim at establishing and sustaining the smoothness of teaching (Herman et al. 2022; Kounin 1970; Kunter et al. 2007; Marder et al. 2023). A lesson is smooth if the teacher effectively manages classroom behavior and instruction (e.g., decreasing interpersonal conflicts, productively handling disruptions during a lesson) to maintain a high level of student engagement and minimize disruptions. For instance, Korpershoek et al. (2016) found an effect of $g = 0.22$ on students' academic, behavioral, and social-emotional outcomes. Therefore, teachers need to be aware of what is happening in their classrooms (i.e., to monitor) and be able to respond promptly to any issues that arise. For instance, teachers must be aware of students' disruptive behavior when monitoring (Marder et al. 2023). Regarding TET, especially the impact of technology on the smoothness of teaching is a subject of controversy (Bolick and Cooper 2011). On the one hand, technologies exist dedicated to increasing the organization and smoothness of a lesson, such as a classroom management tool that enables easy tracking of students' learning progress (Scheiter 2021). On the other hand, technologies might induce new challenges and disruptions as there might be new technical problems and distractions by the technologies (Bolick and Cooper 2011; Meinokat and Wagner 2022). Meinokat and Wagner (2022) elaborated that the success of all strategies for classroom management in TET requires that teachers feel comfortable with TET, which may include teachers being able to use technology smoothly. Therefore, successful classroom management—in non-TET and TET—can be defined as high levels of student work involvement and low levels of disruption during a lesson (Doyle 1985), which potentially leads to students spending more time on tasks, having more positive emotions while learning, and showing more in-depth

processing of tasks, which ultimately may lead to more understanding and motivation while learning (Klieme et al. 2009).

1.2 Teachers' competencies as a boundary condition for technology integration

Teachers' professional competencies were emphasized in offer-use models for using technology in teaching as a condition for high-quality TET (Stürmer et al. 2021; for a critical review of models, see Vieluf et al. 2020). Professional competencies are a multidimensional construct that commonly comprises teachers' dispositions like cognitive and motivational antecedents and teachers' beliefs and self-regulation ability (Blömeke et al. 2015; Kunter et al. 2013). Following theoretical models of teachers' learning and performance motivation (e.g., Daumiller 2019), it can be assumed that teachers' motivation (e.g., teachers' situational self-efficacy regarding the use of technology in teaching) and teachers' cognition (e.g., knowledge) are interconnected in a complex manner. Also, Blömeke et al. (2015) stated that teachers' motivations "change during the in-situation performance as the situation moves along" (p. 6). That is, teachers' situational self-efficacy regarding the use of technology in teaching may be affected by teachers' knowledge (e.g., technology-related knowledge) over consecutive lessons.

In the context of technology integration, recent research demonstrated the key role of professional knowledge and motivation for technology integration (Herring et al. 2016; Joo et al. 2018; Koehler et al. 2013; Scherer et al. 2020; Scherer and Teo 2019; van Braak et al. 2004). For instance, it is well known that teachers' professional knowledge (e.g., technological and technological pedagogical knowledge) is essential for how often and how teachers use technology in the classroom (Harris et al. 2009; Herring et al. 2016; Lachner et al. 2019; Koehler et al. 2013; Mishra and Koehler 2006). Regarding teachers' motivation, Backfisch et al. (2021), for instance, used an experience-sampling approach to investigate the role of teacher motivation on the quality of technology integration over six weeks. The authors used an online teacher diary and asked teachers to weekly document their current motivation (i.e., self-efficacy, utility-value of educational technologies) and the frequency and quality of technology integration using an explanatory mixed-method approach. The authors found considerable variability in teacher motivation and the frequency and quality of technology integration (for related evidence, see Kale 2018; Scherer and Teo 2019). Notably, teachers' perceived utility-value of their technology use was decisive for the quality of technology integration.

1.3 Professional development for integrating technology

The previous findings highlight the role of teacher competencies but, at the same time, suggest the need for PD/OPD interventions to equip teachers with the skills to integrate technology successfully and consistently into their teaching. PD/OPD comprises formal and informal learning opportunities that aim at widening and improving teachers' competencies, such as knowledge and motivation (Desimone 2009; Richter et al. 2011; Sims et al. 2023). The importance of technology-related PD/OPD is especially emphasized as a crucial step in preparing in-service teach-

ers for high-quality TET (Eickelmann et al. 2021; Fernández-Batanero et al. 2020; Fütterer et al. 2023b; Hillmayr et al. 2020; Lawless and Pellegrino 2007; Petko et al. 2018; Tondeur et al. 2016; Ertmer and Ottenbreit-Leftwich 2010). For instance, Konstantinidou and Scherer (2022) demonstrated that teachers' participation in technology-related PD is related to their instructional practices. Teachers who participated in technology-related PD simultaneously adopted high-quality instructional strategies more frequently and emphasized professional competencies (i.e., digital skills) more than other teachers. In many technology-related PD/OPD interventions, new technologies or approaches to using technologies for teaching have been introduced (Fraillon et al. 2020). This circumstance implies that teachers are often confronted with new knowledge and concepts that may change their workflows of TET. According to Lewin (1947), such changes from a known to an unknown state can be described in three phases (see also Hussain et al. 2018): 1) *unfreezing*, 2) *changing*, and 3) *refreezing*. Unfreezing is the initial stage, which includes planning and readiness for the change process. In changing teaching from traditional (analog) teaching to TET, teachers must question regular lesson design and rethink how technology can be integrated into teaching to achieve students' learning objectives (unfreezing). Afterward, teachers must try to adapt their ideas and plans of TET in the classroom (changing). In this phase, teachers learn what works and what does not in terms of practical implementation and given conditions (e.g., infrastructure, student use of technology). If teachers are convinced that technology may help them and their students in some teaching and learning situations, teachers are more likely to try the new approaches (Konstantinidou and Scherer 2022; Scherer et al. 2019, 2020) demonstrated in a technology-related PD. That is, trial and error is also part of this phase, which increases the probability of interruptions in the flow of teaching, for instance, when students do not use the features of an application as intended. Nonetheless, the more routine is established, and the more experience is gained with TET, the smoother teaching will run again, and thus consolidation takes place (freezing).

However, studies on how teaching looks when teachers implement new information in their professional practice during PD/OPD are scarce. For instance, regarding technology-related PD/OPD, it is an open question how well teachers manage to translate the information from the PD/OPD into high-quality (e.g., smoothness) technology-enhanced teaching while participating in a PD/OPD. Specifically, there need to be longitudinal studies in which teachers' trajectories are examined closely regarding their TET to gain insights into change processes and to determine the quality of TET and teachers' motivation during a PD/OPD program. Insight into the development of TET during PD/OPD is important, for instance, to obtain information on the customized mechanisms of PD/OPD effects and to be able to adapt PD/OPD specifically to individuals. In line with this, researchers have recently emphasized the importance of extending from cross-sectional to longitudinal perspectives, mainly when questions related to developing technology-related skills are in focus (Gnamb 2021).

1.4 Research questions

In this study, we aim to gain detailed insights into intra-individual changes in teachers' technology integration and motivation during instructional phases of OPD on the high-quality use of technology in teaching. Therefore, we focused on the phases of OPD in which teachers are confronted with new approaches to the high-quality design of TET, described in Lewin's change model as the unfreezing and changing phases. More specifically, we addressed the following research questions (RQs):

RQ1 *How do teachers' a) intra-individual technology integration (frequency, quality) and b) motivation (self-efficacy, utility value) vary during participation in a technology-related online professional development program?*

RQ2 *How do individual prerequisites (i.e., technology-related knowledge) and institutional contexts (e.g., number of students) predict technology integration and motivation?*

RQ3 *Which processes underlie possible different patterns in teachers' technology integration and motivation during participation in the online professional development program?*

2 Method

2.1 Procedure

Our study is based on an OPD that aimed at preparing teachers to conduct high-quality TET. The 12-week OPD was composed of two main phases. The first phase lasted four weeks (May 2021) and focused on the instructional theories and models for the high-quality use of technology in the classroom. This phase corresponds to Lewin's change model's unfreezing and changing phases. In the second phase, which lasted eight weeks (June and July 2021), teachers were involved in self-study and group sharing activities, in which they were asked to reflect on the use of technology in their teaching. This phase corresponds to the refreezing phase of Lewin's change model, as this phase targets the consolidation of routines for technology use in the classroom. The OPD was organized via the learning management software Moodle.

We utilized an experience-sampling approach using data from four measurement points within the first phase (i.e., t_0 , t_1 , t_2 , t_3). Those were the weeks when teachers received instructions on the high-quality use of technology in teaching (Fig. 1). We focused on the first phase because we assumed that this phase was crucial as during this period, teachers were presented with all information of the whole OPD and, thus, exposed to novel concepts of TET and corresponding teaching strategies. Therefore, we expected changes in the use of technology among the participants, particularly in this phase. A novelty effect regarding teachers' motivation could be assumed, often leading to high initial motivation when individuals encounter new information. This heightened motivation can be particularly beneficial at the

| Timeline and Phase | Week 1 | | Week 2 | | Week 3 | | Week 4 | |
|-----------------------------------|---|---|--|--|---|--|---|--------------|
| | Pretest | Kick-Off | Input 1 | Self-Study 1 | Input 2 | Short Survey | Self-Study 2 | |
| Duration | 84' | 45' | 45' | 60' | | 45' | 15' | |
| Synchronous / Asynchronous | asynchronous | synchronous | asynchronous | asynchronous | asynchronous | asynchronous | asynchronous | asynchronous |
| Reflection Diary | | | Week 1 | Week 2 | Week 3 | Week 4 | | |
| Goal and Content | Assess the prerequisites with which the participants start the online professional development. | Getting to know each other, motivation, goals, and organization | Theory and Empiricism: Technology in Classrooms | Technology in the classroom | How to use technology in the classroom? | The participants' intermediate status regarding, for instance, their technology-related self-efficacy. | Creating an individual lesson plan | |
| Strategy and Methods | An online survey (self-reports and tests) using the Unipark software. | Online meeting using BigBlueButton; Breakout small group discussions in breakout rooms; Instruction using Powerpoint, Question and answer sessions; Short individual self-assessment regarding TPK via Unipark; Processing a task sheet in group work | Using the learning management software Moodle, a recorded instructional video (lecturer visible in the video), key papers, and a feedback form (bitfeedback.de) were provided. | Using the learning management software Moodle, a recorded instructional video for self-study (lecturer visible in the video), a digital worksheet with three tasks, and an optional additional task as well as literature were provided. | Using the learning management software Moodle; a recorded instructional video (lecturer visible in the video) and a guide for strategically selecting technology and key papers were provided. A positive list of technologies (i.e., technology that complies with data protection regulations) was provided via padlet.com. | An online survey (self-reports) using the software Unipark. | Using the learning management software Moodle, a recorded instructional video for self-study (lecturer visible in the video), a digital worksheet with two tasks, and an optional additional task was provided. | |

Fig. 1 Overview of the Schedule for the First Four Weeks of the Online Professional Development

beginning of the instructional phase of the OPD, potentially influencing how teachers absorb and engage with the presented material. In addition, we assumed a greater variance in the scenarios of the use of technology in the classroom in this phase. Therefore, we hoped to identify the challenges of changing from the routines of analogically designed teaching to TET.

The OPD was developed along with current evidence from instructional psychology and based on key characteristics of high-quality OPD (e.g., scaffolding, active learning). Teachers were invited to work on an online reflection diary adapted from Backfisch et al. (2021) throughout the OPD. The purpose of using the reflection diary was twofold: to help teachers become aware of how they use technology in their teaching and to give deep insights into how the teachers' technology integration process and experiences. For this purpose, the teachers were asked to reflect on their use of technology in the classroom each week (about a 15-minute reflection). The weekly reflections addressed, for instance, how frequently teachers used technology in teaching in the past week, which technology (e.g., applications) was used, how self-efficacious teachers are in using technology in teaching, or how much they enjoy teaching with technology. Teachers received feedback on their weekly responses in progress charts as part of the online reflective diary.

2.2 Sample

The teachers who participated in the OPD represent an opportunity sample. For the present study, we identified all teachers who regularly filled in the reflection diary and provided the necessary information in the pretest and posttest. This approach resulted in a sample of $N=23$ teachers for the quantitative analyses. On average, these teachers were $M=43.17$ years old ($SD=10.52$; min=26; max=64) and had $M=14.74$ years of teaching experience ($SD=9.94$; min=1.12; max=37.56). 74% of teachers identified as female. Using two-sided *t*-tests, we found no statistically significant differences in the constructs used in this study (e.g., utility value, self-efficacy, TPK, TK) at the pretest nor at the first measurement point in the reflection diary between the 23 teachers who participated in the reflection diary and those who did not.

The teachers taught various subjects (e.g., chemistry, German). Teachers were asked to assign themselves to one of five profiles of familiarity using technology (i.e., digital media and software programs and applications) in teaching (i.e., inexperienced, novice, advanced, pragmatist, enthusiast) in a closed item during the first week of the reflection diary (see our Open Science Framework [OSF] project (<https://doi.org/10.17605/OSF.IO/QH8SK>) for the exact item wording; Fütterer et al. 2024). Regarding teachers' familiarity, three teachers described themselves as *novices* who have had their first experience with technology but are not yet very familiar with it. 15 teachers described themselves as *advanced users*, using technology occasionally in teaching and feeling confident in the basic operation of it. Five teachers described themselves as *pragmatists* who frequently use technology in teaching, especially if it means a methodological gain. That is, they are aware of the strengths and weaknesses of the technology.

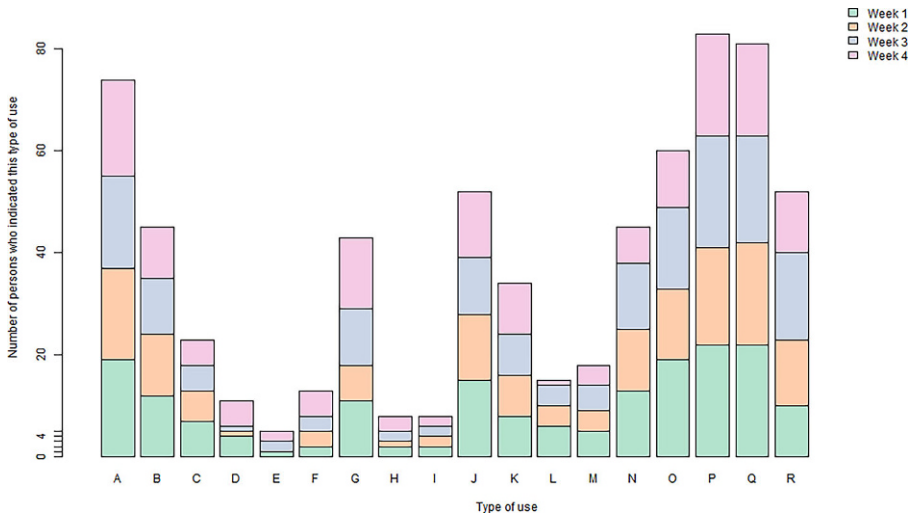


Fig. 2 Type of Use of Technology per Week. (*A* present something yourself (e.g., in PowerPoint), *B* have the students present something, *C* working with students using word processing programs, *D* read digital textbooks with students, *E* work with students using spreadsheets or databases, *F* create graphics with students (e.g., diagrams, concept maps, sketches, authentic representations), *G* do some research with the students on the internet, *H* program something with the students, *I* have students work with simulations, *J* have students communicate using internet technologies (e.g., email, chat, forums), *K* play educational games with students, *L* have students make audio/video recordings, *M* listen to music with students, *N* review or assess student learning performance, *O* check students' homework or assign homework, *P* organize and provide teaching materials, *Q* prepare my lessons, *R* follow up on my lessons)

The number of teachers per teaching or learning activity remained stable across the four measurement points (Fig. 2). Teachers most often used technology to organize and provide teaching materials. They rarely used technology to work with students using spreadsheets or databases, to program something with the students, or to have students work with simulations.

To identify a reasonable subsample for the qualitative analyses, the maximum variation approach by Palinkas et al. (2015) was applied based on the sample determined for the overall quantitative analyses. One of the authors identified teachers who differed based on the trajectories of their quality of technology integration across the weeks to be able to represent the diversity of the teachers and then discussed this sample with all authors. The resulting subsample consisted of four teachers with different backgrounds and experiences during their technology integration, see Table 1.

2.3 Measures

2.3.1 Quantitative data: dependent variables

The dependent variables included teachers' technology integration (i.e., frequency and quality) and their motivation for using technology in the classroom (i.e., self-efficacy, utility value). All four measures were adopted from Backfisch et al. (2021).

Table 1 Characteristics of Teachers for Qualitative Analysis

| Name | Age | Subjects | Familiarity | Main pattern |
|-------|-----|-------------------------|---------------|---|
| Sara | 53 | German (first language) | Advanced user | Minimalism leads to smoothness; difficulty leads to frustration |
| Julia | 42 | Music and mathematics | Advanced user | Simplicity leads to smoothness; complexity leads to frustration |
| John | 35 | Social studies | Pragmatist | Familiarity leads to smoothness |
| Steve | 63 | Economics | Advanced user | Domain-specific tools lead to smoothness |

Experience level was self-rated. Advanced user means teacher uses digital media/applications occasionally in teaching and feels confident in basic handling; Pragmatist means teacher likes to use digital media/applications frequently in teaching, especially if it means a methodological gain, and he is aware of the strengths and weaknesses of digital media)

Technology integration We assessed the *frequency* of teaching with technology with one item (“In how many lessons did you use technology during the last teaching week [please calculate one lesson per 45 min]? I have used technology in * of ** lessons”). The * represents the number of lessons in which technology was used, and the ** is the total number of lessons in the last teaching week. We calculated a percentage from 0 (*technology was used in no lesson*) to 100 (*technology was used in all lessons*).

Regarding the *quality* of technology integration, we particularly focused on smoothness as an indicator of classroom management with one item (“The use of technology in teaching worked smoothly”) adopted from Backfisch et al. (2021), which was rated on a 5-point rating scale ranging from 1 (*does not apply*) to 5 (*applies*).

Motivation To assess teachers' *self-efficacy* regarding the use of technology for teaching, we used a scale comprising four items (e.g., “When I used technology in teaching during the last week, I was calm about the potential difficulties of using technology”) adopted from Backfisch et al. (2021). Teachers rated these items on a 4-point rating scale ranging from 1 (*not true at all*) to 4 (*exactly true*). Following Taber (2018), the internal consistency of this respective self-efficacy scale was good for the 23 teachers in this study ($\alpha=0.74$).²

We used two items to assess teachers' perceived *utility value* of technology for teaching (e.g., “When I used technology in teaching last week, I found that technology was useful for my teaching”; Backfisch et al. 2021; adapted from Rigotti et al. 2008). Teachers rated these items on a 4-point scale ranging from 1 (*not true at all*) to 4 (*exactly true*). The internal consistency (Spearman's rank correlation ρ) of this respective utility scale was good for all teachers participating in the OPD ($\rho=0.58$) but only acceptable for the 23 teachers used for this study ($\rho=0.46$). The reliability was not expected to be high for this scale because there were only two items and reliability depends on the number of items.

² The alpha value is the mean value of the alpha values per week.

2.3.2 Quantitative data: independent variables

The independent variables included teachers' cognitive prerequisites (i.e., technological and technological pedagogical knowledge) and contextual characteristics (i.e., teaching load, number of students, and the function of the teacher). All items are shown in our OSF project.

Cognitive prerequisites We tested teachers' *technological knowledge (TK)* before the OPD started. We used a Rasch-scaled test comprising 26 items to assess teachers' technological operating skills (Fütterer et al. 2023c). Weighted likelihood estimates (WLEs; Warm 1989) represent teachers' test performance.

We tested teachers' *technological pedagogical knowledge (TPK)* with eight open test items based on a test using closed-answer formats as presented and used by Fütterer et al. (2023c). For different teaching situations, teachers were asked how and whether technology can be used didactically in a meaningful way to support teaching-learning processes. Two trained raters rated the teachers' answers on three dimensions (weighted Cohen's κ for two raters = 0.77; Cohen 1968): teaching quality, utilization of the potential of technology, and quality of the justification. A maximum of three points could be achieved per task. A total sum score represented the test performance.

Contextual characteristics To assess the *teaching load*, we asked teachers whether they worked with a *reduced teaching load* (= 0) or a *full teaching load* (= 1). Teachers indicated the *number of students* attending their school by answering on a 6-point rating scale ranging from 1 (≤ 200 students) to 6 (≥ 1000 students). To capture the *function of a teacher*, we asked teachers whether they are part of the school leadership team (= 1) or not (= 0).

2.3.3 Quantitative data: covariates

In our models, we controlled for teachers' gender ("Please indicate your gender"; 0 = male, 1 = female, 2 = diverse³) and teachers' self-reported *time in the profession* ("Please indicate how long you have been in the teaching profession"; continuous in years). The wording of all items is provided in our OSF project.

2.3.4 Qualitative data: weekly reflection

Within the teacher diary, teachers were asked to reflect on their TET with the following prompts (for equivalent approaches, see Backfisch et al. 2021):

To help us better understand how you use educational technology in your classroom, please select one of your lessons below and describe it in more detail. You should have used educational technology at least once in this lesson. If

³ No participant chose the category diverse, which is why we used a dichotomous variable 0 = male, 1 = female in the analyses.

you have used educational technology in several lessons, please select the one that you think was the most successful. Please describe this lesson in more detail. The following guiding questions may help you to do so:

- What (main) teaching objectives did you pursue?
- To what extent did using educational technology support your teaching objectives?
- In which teaching phase did you use educational technology?
- Which didactic methods did you use?

In addition, we asked teachers to provide additional information about the lesson described, such as the grade, the subject, or the topic. The average word count of the lesson documentation was 145 words, with a standard deviation of 48 words. For the analyses of the reflections, we followed an inductive and iterative coding approach (Braun and Clarke 2006). We identified individual codes, patterns, and overarching themes of the teachers' reflections.

2.4 Statistical analyses

To answer the three research questions and to ensure an in-depth understanding of the change in teachers' technology integration and motivational tendencies in the context of a multi-week OPD, we used triangulation (Denzin 2012) and substantial integration of quantitative and qualitative methods (concurrent explanatory mixed method approach; Woolley 2009). We used quantitative methods to answer the first two research questions to obtain an overall picture of change in technology integration and motivational tendencies across all teachers. To answer the third research question, we utilized weekly reflections.

2.4.1 Quantitative analyses

We performed all statistical analyses with the *R* statistical language 4.4.2 (R Core Team 2022) using *RStudio* 2022.12.0 (Posit team 2022). To answer how teachers' intra-individual technology integration and motivation vary during participation in the OPD program (RQ1), we used, similar to Backfisch et al. (2021), the *R* package *gtheory* 0.1.2 (Moore 2016), which estimates variance components utilizing generalizability theory (cf. G theory). We used a multilevel framework to examine how teachers' technology integration (i.e., frequency and quality) and their motivation regarding the use of technology in the classroom (i.e., self-efficacy, utility value) varied between lessons while accounting for the nested structure of longitudinal data (i.e., four measurement points within persons).

To answer how individual prerequisites (i.e., knowledge) and institutional contexts (e.g., number of students) predict teachers' technology integration and motivation (RQ2), we used linear mixed-effects models (i.e., random intercept and random slope models; see Appendix A for justification). The linear mixed-effects models account for the hierarchical multilevel structure of the longitudinal data. We used the *R* package *lme4* 1.1-31 (Bates et al. 2015) and *lmerTest* 3.1-3 (Kuznetsova et al. 2017) to estimate these models. We computed the models separately for each

of the four dependent variables. We structured each of them stepwise by using intercept-only models in the first step (M0), including covariates in the next step (M1), and including the independent variables as predictors in the final step (M2). M2 is a random intercept and random slope model as we included independent variables as fixed effects except for time which we included as a random effect. These nested models were compared by deviance using likelihood ratio (LR) tests. We used restricted maximum likelihood (REML; Corbeil and Searle 1976) as REML provides unbiased variance estimates (especially when the number of groups is small; Swaminathan and Rogers 2008). As only 0.41% of the 1472 values in the longitudinal data were missing, we applied no treatment of missing values. The complete reproducible code and data used for this study can be found in our OSF project (see link above).

2.4.2 Qualitative analyses

We qualitatively analyzed the teachers' weekly reflections to better understand the quantitative results and to obtain deep insights into teachers' experiences during their technology integration. Within the reflections of the identified teachers, we identified themes and patterns of each teacher across the weeks and overarching themes between the teachers.

To inductively identify these themes and patterns, we adopted the six-step thematic analysis procedure by Braun and Clarke (2006). First, all authors individually read all reflections of the selected teachers to get an overview of their experiences. Second, two of the authors identified patterns across the reflections of each teacher and iteratively generated codes to describe these patterns. Third, we combined different codes to identify overarching themes by incorporating codes from the reflections of different teachers. Fourth, we discussed these overarching themes with all authors, and, fifth, one of the authors checked in an iterative loop the alignment of the themes with each reflection to ensure the fit between identified themes and original data (i.e., written reflections). Finally, in the sixth step, we wrote up the report of the qualitative analyses. Across all steps, we applied a peer debriefing strategy by discussing our findings within the groups of authors, thereby identifying and resolving potential dissimilar interpretations to heighten our qualitative findings' trustworthiness and validity.

3 Results

3.1 Teachers' technology integration and motivation

To gain insight into how teachers' technology integration and motivation varied during their participation in a technology-related PD (RQ1), we first inspected the descriptive statistics of all four dependent variables at all four measurement points (Table 2; Appendix B). Notably, teachers' technology integration and motivation (i.e., all dependent variables) at the fourth measurement point (t_3) were lower on average than at the previous measurement points. In addition, the variance of all

Table 2 Descriptive Statistics of Dependent Variables for all Four Measurement Points

| Week/DV | Frequency | | | Smoothness | | | | | Self-efficacy | | | | | Utility value | | | | | | |
|-----------------------------|-----------|-------|-------|------------|-----|----|------|------|---------------|-----|----|------|------|---------------|------|----|------|------|------|------|
| | N | M | SD | min | max | N | M | SD | min | max | N | M | SD | min | max | N | M | SD | min | max |
| Week 1 (t ₀) | 23 | 77.25 | 20.68 | 20.39 | 100 | 23 | 4.48 | 0.67 | 3 | 5 | 23 | 3.36 | 0.47 | 2.25 | 4.00 | 23 | 3.48 | 0.49 | 2.00 | 4.00 |
| Week 2 (t ₁) | 22 | 84.17 | 21.28 | 33.33 | 100 | 22 | 4.50 | 0.74 | 3 | 5 | 22 | 3.27 | 0.47 | 2.50 | 4.00 | 22 | 3.41 | 0.57 | 2.00 | 4.00 |
| Week 3 (t ₂) | 23 | 83.15 | 24.08 | 25.00 | 100 | 23 | 4.43 | 0.84 | 2 | 5 | 23 | 3.52 | 0.46 | 2.50 | 4.00 | 23 | 3.43 | 0.61 | 1.50 | 4.00 |
| Week 4 (t ₃) | 23 | 72.94 | 31.37 | 0 | 100 | 22 | 3.86 | 1.52 | 0 | 5 | 22 | 3.16 | 0.68 | 1.75 | 4.00 | 22 | 3.32 | 0.61 | 2.00 | 4.00 |

Frequency is reported as a percentage. Smoothness was assessed with one item and a response scale from 1 to 5, and self-efficacy as well as utility value was assessed on a response scale from 1 to 4 DV dependent variable

dependent variables was largest at the fourth measurement point. In addition, Fig. 3 illustrates individual trajectories of teachers' technology integration and motivation to use technology across lessons each week. It becomes apparent that the trajectories vary considerably between individuals and that the levels within an individual also fluctuate across lessons.

Next, we examined the proportions of variance components explained to determine whether the different trajectories were due to teacher characteristics or general time trends. We found that most variances cannot be explained by teacher characteristics or general time progression (residual variance ranging from 58.9 to 81.5%; Fig. 4). This finding suggests that the variance in all four variables is largely due to contextual elements arising from the specific teaching setting.

3.2 Teachers' prerequisites and their technology integration and motivation

To test how individual prerequisites (i.e., knowledge) and institutional contexts (e.g., number of students) predicted teachers' technology integration and motivation regarding the use of technology (RQ2), we conducted a multilevel regression analysis (see Tables 3, 4, 5 and 6). In general, considering covariates did not lead to a statistically significant improvement (M1 compared to M0 when performing chi-square difference tests) of the models. The proportion of total variance between individuals, as measured by the intraclass correlation coefficient (ICC), ranged from 12% (smoothness) to 35% (self-efficacy) across the four dependent variables. The consideration of independent variables (M2) led to a statistically significant improvement of the models regarding teachers' technology integration (i.e., frequency [i.e., percentage; $\chi^2=20.63$, $df=8$, $p=0.008$] and quality [$\chi^2=17.92$, $df=8$, $p=0.022$] of technology use), but not regarding teachers' motivation (i.e., self-efficacy and utility value). However, except for the teaching load predicting teachers' quality of technology integration (i.e., smoothness), where full-time teachers reported more smoothness of technology use than teachers with a reduced workload ($B=0.74$, $p=0.014$), no independent variables showed statistically significant predictive power. For teachers' quality of technology use, the estimated population mean value of the predictive power of time (random slope) was significantly negative ($B=-0.19$, $p=0.039$). This means that the self-reported smoothness decreased on average across the four measurement points.

3.3 Patterns in integrating technology and teachers' motivation: courage leads (first) to chaos

To gain insight into which processes underlie possible different patterns in integrating technology and teachers' motivation during participation in the OPD program (RQ3), we closely inspected the qualitative data. In sum, the quantitative analyses revealed a systematic decrease in the smoothness of technology integration but no systematic change in teachers' frequency of technology use and their motivation. At the same time, there was a high—but unsystematic—variation of teachers' technology integration and motivation between the teachers and within one teacher across

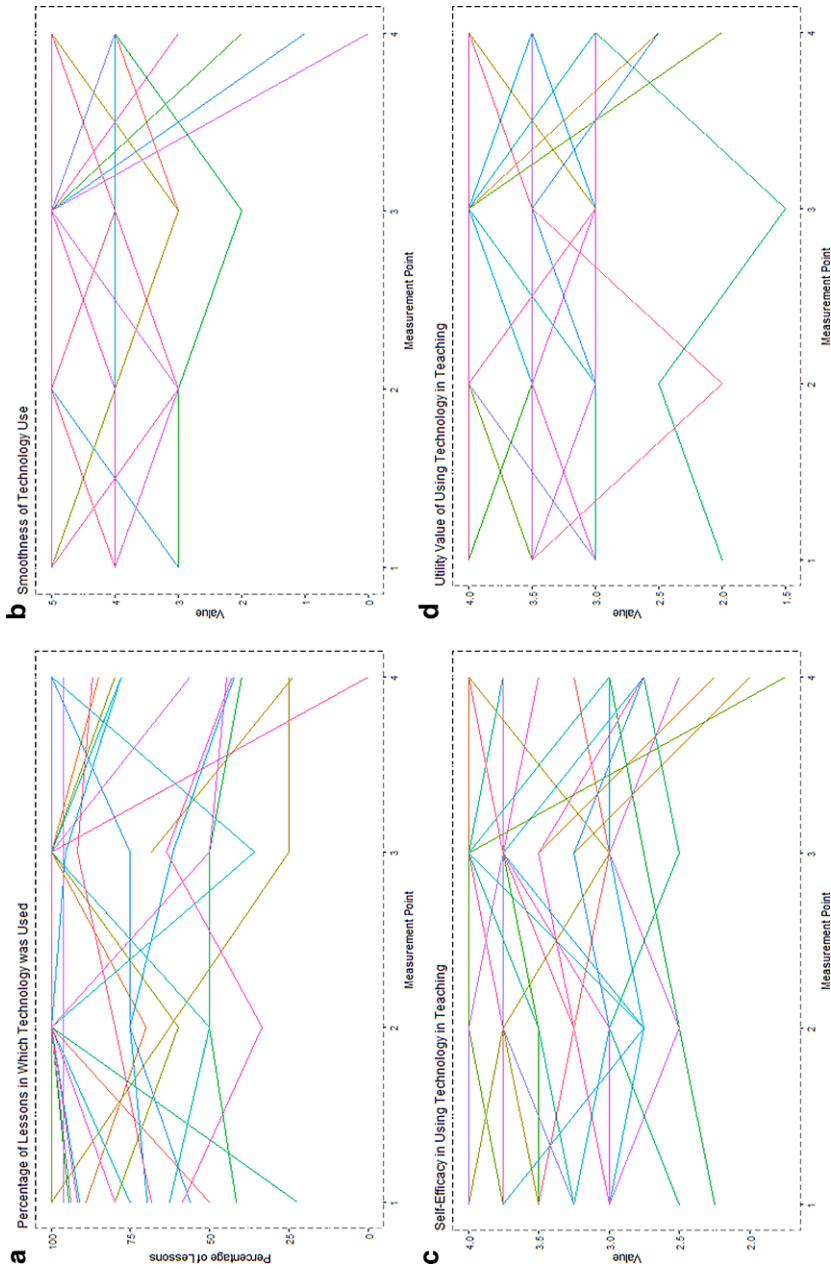


Fig. 3 Teachers' Weekly Technology Integration and Motivation to Use Technology. (N = 23. Each line represents the trajectory of one teacher)

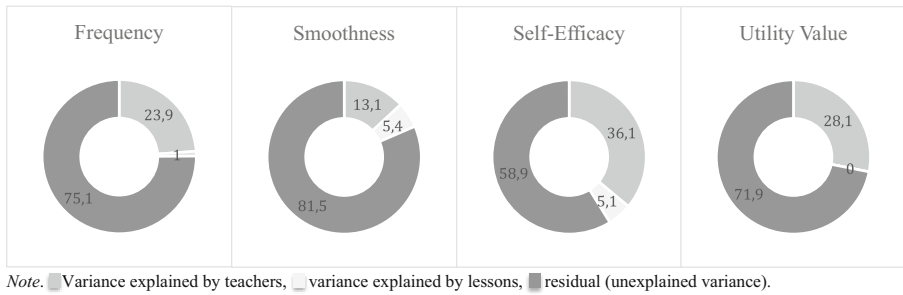


Fig. 4 Explained Variance of Teachers' Technology Integration and Their Motivation to use Technology in Teaching

lessons. This variation might be due to contextual factors subject to qualitative analyses.

Some teachers' reflections suggested that the decrease in smoothness over time might have resulted from teachers—potentially inspired by the OPD—trying new tools and technologies over time. For instance, during the first 3 weeks, Sara's technology use incorporated explaining videos (either self-made or provided by YouTube) or easy-to-use tools such as LearningApps.org, which enables short learning games to be designed by drag-and-drop functionalities. These lessons worked out smoothly, as expected. In the fourth week, however, she tried to program a crossword puzzle with a rather complex web-based application, which resulted in technical problems and frustration:

The goal was to deepen the knowledge of rhetorical figures playfully. I programmed three crossword puzzles using the x-word generator. Even though I saved the puzzles in two different formats at home and saved them online, only half of the students could even open the crossword puzzle. No one could fill it out digitally. This was frustrating because I had invested much time in a 'nice little, playful way,' and it didn't really work. (Sara, Week 4)

Julia shared similar experiences. After she used relatively simple stand-alone digital tools such as explaining videos and audio recordings, in Week 3, she decided to use a digital teaching assistant, which allowed her to orchestrate different tools. However, she concluded, "the digital teaching assistant has not proven itself due to technical difficulties."

In contrast, John mainly used tools that allowed students to work simultaneously in shared documents across different lessons. This collaboration worked quite well, and John himself attributed the smoothness to the familiarity of the procedure: "The class knows this way of working together digitally in one document." In the first weeks, John implemented products from Microsoft but switched to an open-source alternative in the fourth week. He used this new tool for a side note on data protection: "The students liked EduPad [open-source collaboration tool] and want to use it in the future." Similarly, Steve, documented very smooth lessons, in which he integrated mainly domain-specific games, simulations, and ready-to-use digital worksheets.

Table 3 Statistics of Multilevel Regression Analysis to Predict the Frequency of Technology Use

| | M0 | | | M1 | | | M2 | | |
|--|----------|-------------|----------|----------|-------------|----------|--------------------|-------------|----------|
| | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> |
| Fixed effects | | | | | | | | | |
| Intercept | 79.24 | 3.40 | <0.001 | 85.33 | 7.74 | <0.001 | 97.47 | 22.75 | <0.001 |
| Time | - | - | - | - | - | - | -1.34 | 2.63 | 0.615 |
| <i>Independent variables</i> | | | | | | | | | |
| Technological knowledge ^a | - | - | - | - | - | - | 1.69 | 4.69 | 0.724 |
| Technological pedagogical knowledge ^a | - | - | - | - | - | - | -3.44 | 2.34 | 0.162 |
| Teaching load ^b | - | - | - | - | - | - | 0.10 | 6.83 | 0.988 |
| Number of students ^b | - | - | - | - | - | - | 3.04 | 3.86 | 0.443 |
| Function of teacher ^b | - | - | - | - | - | - | 20.90 | 12.80 | 0.123 |
| <i>Covariates</i> | | | | | | | | | |
| Gender ^b | - | - | - | 3.62 | 7.66 | 0.642 | 12.77 | 11.99 | 0.304 |
| Teaching experience ^b | - | - | - | -0.60 | 0.35 | 0.101 | -0.63 | 0.38 | 0.114 |
| Random effects | | | | | | | | | |
| τ_{00} (intercept) | 147.20 | | | | | | Variance component | | |
| τ_{11} (time) | - | | | 135.40 | | | 397.0 | | |
| τ_{10} (correlation) | - | | | - | | | 95.5 | | |
| $\hat{\sigma}^2$ (residual) | 471.10 | | | 471.20 | | | -0.89 | | |
| | | | | | | | 318.90 | | |

N_{Level1} = 91, $N_{Level2_individuals}$ = 23. ICC_{M0} = 0.24, i.e., 24% of the whole variance of the frequency of technology use is between individuals

^a Tested at the pretest

^b Self-reported at the pretest

Table 4 Statistics of Multilevel Regression Analysis to Predict the Smoothness of Technology Use

| | M0 | | | M1 | | | M2 | | |
|--|----------|-------------|----------|----------|-------------|----------|---------------------------|-------------|----------|
| | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> |
| Fixed effects | | | | | | | | | |
| Intercept | 4.32 | 0.12 | <0.001 | 4.48 | 0.30 | <0.001 | 5.46 | 0.89 | <0.001 |
| Time | - | - | - | - | - | - | -0.19 | 0.09 | 0.039 |
| <i>Independent variables</i> | | | | | | | | | |
| Technological knowledge ^a | - | - | - | - | - | - | -0.17 | 0.09 | 0.079 |
| Technological pedagogical knowledge ^a | - | - | - | - | - | - | 0.34 | 0.19 | 0.084 |
| Teaching load ^b | - | - | - | - | - | - | 0.74 | 0.27 | 0.014 |
| Number of students ^b | - | - | - | - | - | - | -0.16 | 0.15 | 0.316 |
| Function of teacher ^b | - | - | - | - | - | - | -0.19 | 0.50 | 0.705 |
| <i>Covariates</i> | | | | | | | | | |
| Gender ^b | - | - | - | -0.18 | 0.30 | 0.554 | 0.80 | 0.47 | 0.111 |
| Teaching experience ^b | - | - | - | 0.00 | 0.01 | 0.875 | 0.01 | 0.02 | 0.460 |
| Random effects | | | | | | | | | |
| $\hat{\tau}_{00}$ (intercept) | 0.12 | | | | | | Variance component | | |
| $\hat{\tau}_{11}$ (time) | - | | | | | | 0.00 | | |
| $\hat{\tau}_{10}$ (correlation) | - | | | | | | 0.01 | | |
| $\hat{\sigma}^2$ (residual) | 0.91 | | | 0.91 | | | 0.85 | | |

$N_{Level1} = 90$, $N_{level2_individuals} = 23$. $ICC_{M0} = 0.12$, i.e., 12% of the whole variance of the smoothness of technology use is between individuals

^aTested at the pretest

^bSelf-reported at the pretest

Table 5 Statistics of Multilevel Regression Analysis to Predict Teachers' Self-Efficacy Regarding Technology Use

| | M0 | | | M1 | | | M2 | | |
|--|----------|-------------|----------|----------|-------------|----------|---------------------------|-------------|----------|
| | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> |
| Fixed effects | | | | | | | | | |
| Intercept | 3.33 | 0.08 | <0.001 | 3.54 | 0.18 | <0.001 | 2.73 | 0.54 | <0.001 |
| Time | - | - | - | - | - | - | -0.03 | 0.05 | 0.568 |
| <i>Independent variables</i> | | | | | | | | | |
| Technological knowledge ^a | - | - | - | - | - | - | 0.17 | 0.11 | 0.162 |
| Technological pedagogical knowledge ^a | - | - | - | - | - | - | -0.01 | 0.06 | 0.786 |
| Teaching load ^b | - | - | - | - | - | - | 0.13 | 0.16 | 0.455 |
| Number of students ^b | - | - | - | - | - | - | 0.10 | 0.09 | 0.297 |
| Function of teacher ^b | - | - | - | - | - | - | 0.30 | 0.31 | 0.348 |
| <i>Covariates</i> | | | | | | | | | |
| Gender ^b | - | - | - | 0.01 | 0.18 | 0.969 | 0.26 | 0.29 | 0.377 |
| Teaching experience ^b | - | - | - | -0.01 | 0.01 | 0.089 | -0.01 | 0.01 | 0.340 |
| Random effects | | | | | | | | | |
| τ_{00} (intercept) | 0.10 | | | | | | Variance component | | |
| τ_{11} (time) | - | | | | | | 0.14 | | |
| τ_{10} (correlation) | - | | | | | | 0.02 | | |
| $\hat{\sigma}^2$ (residual) | 0.19 | | | 0.19 | | | -0.74 | | |
| | | | | | | | 0.16 | | |

$N_{Level1} = 90$, $N_{Level2_individuals} = 23$. $ICC_{M0} = 0.35$, i.e., 35% of the whole variance of self-efficacy regarding technology use is between individuals

^aTested at the pretest

^bSelf-reported at the pretest

Table 6 Statistics of Multilevel Regression Analysis to Predict Teachers' Utility Value Regarding Technology Use

| | M0 | | | M1 | | | M2 | | |
|--|----------|-------------|----------|----------|-------------|----------|----------|-------------|---------------------------|
| | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> | <i>B</i> | <i>S.E.</i> | <i>p</i> |
| Fixed effects | | | | | | | | | |
| Intercept | 3.41 | 0.08 | <0.001 | 3.49 | 0.18 | <0.001 | 3.50 | 0.57 | <0.001 |
| Time | - | - | - | - | - | - | -0.04 | 0.05 | 0.378 |
| <i>Independent variables</i> | | | | | | | | | |
| Technological knowledge ^a | - | - | - | - | - | - | 0.19 | 0.12 | 0.134 |
| Technological pedagogical knowledge ^a | - | - | - | - | - | - | -0.05 | 0.06 | 0.431 |
| Teaching load ^b | - | - | - | - | - | - | -0.23 | 0.17 | 0.201 |
| Number of students ^b | - | - | - | - | - | - | 0.01 | 0.10 | 0.920 |
| Function of teacher ^b | - | - | - | - | - | - | 0.02 | 0.32 | 0.951 |
| <i>Covariates</i> | | | | | | | | | |
| Gender ^b | - | - | - | 0.19 | 0.18 | 0.300 | 0.45 | 0.30 | 0.159 |
| Teaching experience ^b | - | - | - | -0.01 | 0.01 | 0.074 | -0.01 | 0.01 | 0.379 |
| Random effects | | | | | | | | | |
| $\hat{\tau}_{00}$ (intercept) | 0.09 | | | | | | | | Variance component |
| $\hat{\tau}_{11}$ (time) | - | | | | | | | | 0.01 |
| $\hat{\tau}_{10}$ (correlation) | - | | | | | | | | 0.00 |
| $\hat{\sigma}^2$ (residual) | 0.23 | | | 0.23 | | | | | 1.00 |
| | | | | | | | | | 0.22 |

$N_{Level1} = 90$, $N_{Level2_individuals} = 23$. $ICC_{M0} = 0.28$, i.e., 28% of the whole variance of utility value regarding technology use is between individuals

^aTested at the pretest

^bSelf-reported at the pretest

Across the individual patterns of the teachers, two overarching themes were identified as decisive factors for successful and smooth technology integration: The lessons may proceed smoothly if 1) the teachers focused on the use of one generic tool across lessons, such as apps for collaboration (e.g., EduPad) or brainstorming (e.g., flinga) so that teachers and students are familiar with its handling and affordances or 2) teachers implement ready-to-use domain-specific tools and software to teach distinct concepts (e.g., simulation games, interactive school books).

4 Discussion

Technology-related PD/OPD is a crucial strategy to support and encourage teachers' technology integration in teaching. However, previous studies on technology-related PD/OPD were mainly based on cross-sectional data, which prevent insights into individual trajectories of teachers' technology integration and change processes of technology-enhanced teaching (TET) during PD/OPD. In this study, we investigated individual trajectories in teachers' technology integration (i.e., frequency and quality) and motivation (i.e., self-efficacy and utility value) during the 4-week instructional phase of a 3-month OPD on high-quality use of technology in teaching. The results indicated that teachers' smoothness of TET decreased when confronted with strategies to implement new technologies and that this decrease could probably be explained by contextual characteristics such as the kind of technology teachers were using (e.g., one generic technology across lessons or the use of ready-to-use domain-specific technology).

The results of the decrease in smoothness correspond to findings on learning new strategies. Learning new strategies often leads to a motivational valley because current routines do not apply, and new routines must first be established (Hasselhorn and Gold 2017; Miller and Seier 1994). From research on the teachers' induction phase when they begin to teach independently, it is known that this phase leads to a decline in self-efficacy beliefs, exhaustion, and a regular "reality shock" (Voss and Kunter 2020). Similarly, in this phase of newly introducing technologies into teaching, teachers first must establish new routines and might be kind of disoriented and low in motivation. Moreover, teachers might perform a reality check of their perceived self-efficacy beliefs and their experienced self-efficacy during teaching with technologies, which possibly leads to a decrease in their indicated self-efficacy as there might have been an overestimation in the first place. This finding is also in line with Lewin's (1947) change model, where particularly in the changing phase, it might also be plausible that smoothness decreases during the instructional phase of PD because new approaches (in this case, the use of technology in teaching) are explored that do not always work as smoothly as planned (trial and error).

Correspondingly, the importance of teachers' teaching load was evident. Full versus reduced teaching load was positively related to the perceived smoothness of TET. This finding might indicate that teachers with a higher teaching load had more opportunities to try out new strategies for using technology to deliver high-quality TET. Moreover, the teachers with higher teaching load might have been able to adapt and integrate the newly learned content on TET from the OPD, as they had a richer

amount of deliberate practice (Berliner 2001) that could result in more applicable curriculum scripts (Pauli and Reusser 2003) as compared with teachers with lower teaching load. Research showed that teaching experience leads to more flexibly organized knowledge structures that can be easily adapted to diverse situations (for an overview, see Lachner et al. 2024; Wolff et al. 2021). Consequently, teachers with higher teaching loads might have been more able to apply this content than teachers with lower teaching loads. That is, these teachers may have more quickly become proficient regarding TET. Further, individual trajectories of teachers' technology integration and motivation to use technology in their teaching across the first weeks of the technology-related OPD were evident (Fig. 3). These individual trajectories were largely due to contextual factors that may include technical problems, types of technology used, or the varying complexity of teaching scenarios. These findings align with previous research (Backfisch et al. 2021).

4.1 Limitations and future directions

Several limitations must be considered for an adequate evaluation of the results. First, we used a selective, small sample. A generalization of the results beyond the sample is thus limited. For instance, few math teachers were included in the sample: This may be one reason why the teachers rarely used technology to collaboratively work with data or code (e.g., via spreadsheets, databases, or simulations). Whereas the results of this study provide good insight into the change processes of TET during participation in a technology-related OPD, future research should utilize a broader sample to examine whether the findings can be generalized across samples to ensure the validity of our findings.

Second, the study focused on only the first phase of the OPD program. Therefore, statements on the further development of TET during the technology-related OPD are not possible. Future studies should apply an experience-sampling approach throughout and even beyond the duration of a PD/OPD. This might help to gain more comprehensive insights into long-term developments beyond the initial unfreezing and changing phases (i.e., into the freezing phase; Lewin 1947). Moreover, future studies could investigate the impact of different institutional contexts on teachers' technology integration and motivation. Logfile data and learning analytics approaches could provide even more detailed insights into OPD usage patterns in the future.

Third, only specific context variables (e.g., number of students) are available. Other variables were not assessed, such as *IT equipment*, *pedagogical support*, or *the schools' vision*, which may play an important role in implementing technology in the classroom (omitted variable bias). At the same time, the residual variance in our assessments of technology integration (i.e., frequency and quality; see Fig. 1) indicates that the majority of the variability cannot be attributed to teacher characteristics or overall temporal trends. Instead, it is largely associated with situational factors arising within the educational context (e.g., teaching environment). Therefore, future research should cover the context more broadly when conducting a PD/OPD to gain better insight into the implementation processes (e.g., teachers' motivation to implement PD/OPD content into practice; Osman and Warner

2020; Sims et al. 2023) and conditions for success and challenges and, thus, the effectiveness of PD/OPD for the teaching practice. For instance, it would also be interesting to analyze PD/OPD characteristics (structural features like compulsory versus non-compulsory or effectiveness factors like duration, coherence, or content focus) more intensively and to systematically vary such characteristics in studies to assess their importance for PD/OPD effectiveness (e.g., regarding the quality of TET) as increasingly recommended (e.g., Sims et al. 2023). Another promising approach would be to gain a more comprehensive insight into the context of teachers (e.g., family commitments).

Fourth, due to the small number of participating teachers, it can be assumed that the power of the linear mixed models is insufficient. This is also confirmed by posterior analyses of the four full models (i.e., M2 for each dependent variable) that we conducted using the *R* package *simr* 1.0.7 (Green and MacLeod 2016). That is, we had an insufficient sample size to detect the effects we were investigating. However, our study can still offer valuable insights and contribute to research in several ways. For instance, our study provides initial observations and trends on teachers' use of technology while participating in a technology-related OPD that can form the basis for future research (i.e., formulating hypotheses that can be tested in more rigorously designed, adequately powered studies). In addition, although individual underpowered studies may not provide definitive evidence on their own, their results can be included in meta-analyses. That is, when combined with the results of other studies, they contribute to a more comprehensive understanding of the research question.

Finally, the study focused solely on teachers' self-reported use of technology, which may be subject to response bias. For instance—although we have no indications of difficulties with the validity of the items we used based on findings from previous studies (e.g., Backfisch et al. 2021)—it could be that different participants understand different things by the term *smoothness*. Therefore, it may be beneficial to consider refining the concept of 'smoothness' in future research to accommodate different contextual nuances and explore potential associations between integrating technology and specific teaching tools and learning objectives. In addition, future research could consider using more objective methods to measure technology integration, such as classroom observations or student ratings.

4.2 Implications for theory and practice

The study findings have important implications for technology-related OPD theory and practice. However, these implications should be approached with caution due to the study's low power.

Regarding theory, the findings on the decrease in smoothness were coherent with Lewin's change model. Thus, the phases of the change model might be suitable for describing changes in teachers' teaching practices during participation in an OPD. Furthermore, findings on individual trajectories of teachers' technology integration and motivation across OPD may provide greater awareness of the level of abstraction of linear models of PD/OPD effectiveness, such as those proposed by Desimone (2009) or Quinn et al. (2019), that are often used in PD/OPD effectiveness research.

How PD/OPD works for a teacher is individually determined. Thus, the findings reinforce efforts to develop theoretical models that are applicable to differentiated or adaptive PD/OPD, in which teachers' individual cognitive and motivational characteristics are addressed before and during PD. The abovementioned potential of logfile data in future OPD research, such rich data have the potential to form the basis for models of adaptive OPD.

Regarding OPD practice, the findings on the decrease of TET smoothness may raise the attention to unintended side effects of technology integration in teaching in the entry phases of technology-related OPD. For OPD providers, the findings emphasize the importance of ongoing support and feedback during OPD programs where new TET strategies are learned—similar to support teachers need during a systematic induction phase (Voss and Kunter 2020).

Moreover, the findings have important implications for the design and delivery of OPD programs and the allocation of resources. According to the teacher trajectories of technology integration in teaching, developing adaptive (technology-related) OPD seems promising, in which individual needs, learning paths, and the diverse contexts in which the teachers teach can be addressed. In this regard, OPD and machine learning approaches might have great potential to organize adaptive OPD that is more flexible, accessible, and cost-efficient.

5 Appendix

5.1 Appendix A

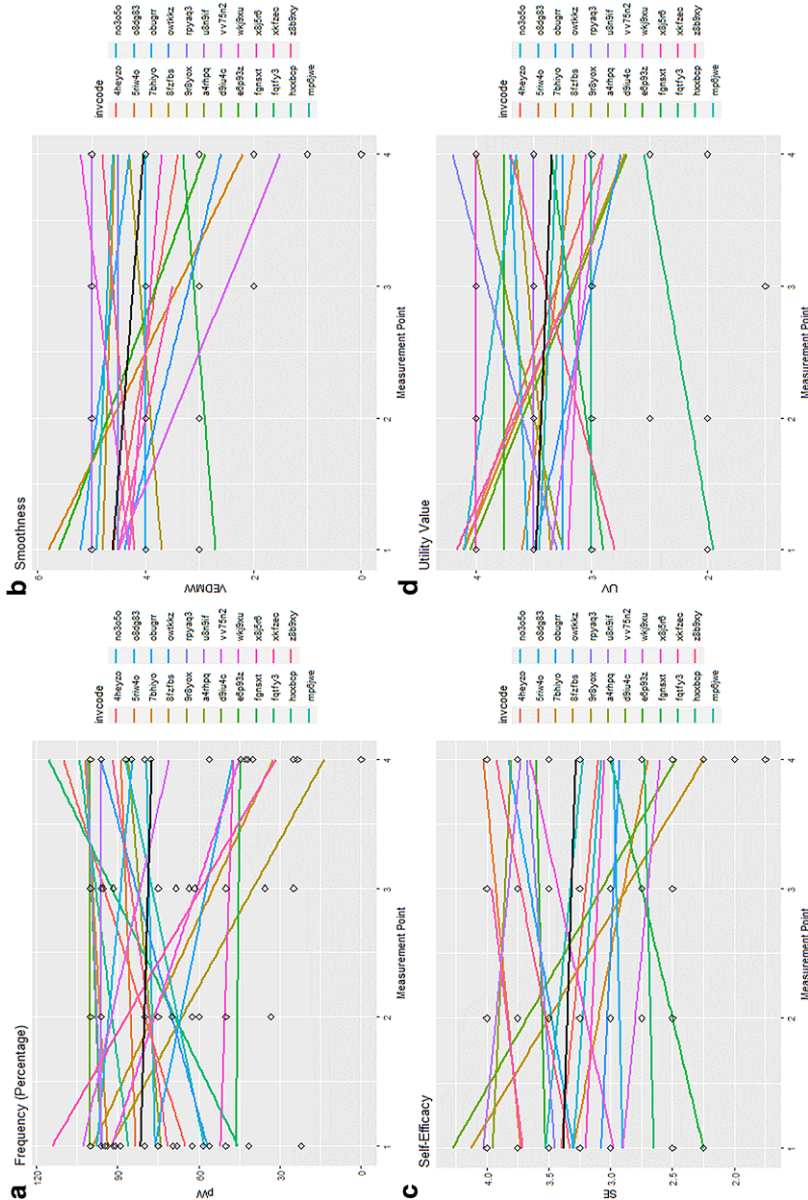


Fig. A.1 Linear Regression of all Four Dependent Variables on Time per Participant. ($N=23$. Each line represents the trajectory of one teacher. Subjects appear to vary in the slopes and intercepts, which suggests a model with random slopes and intercepts for all four dependent variables)

5.2 Appendix B

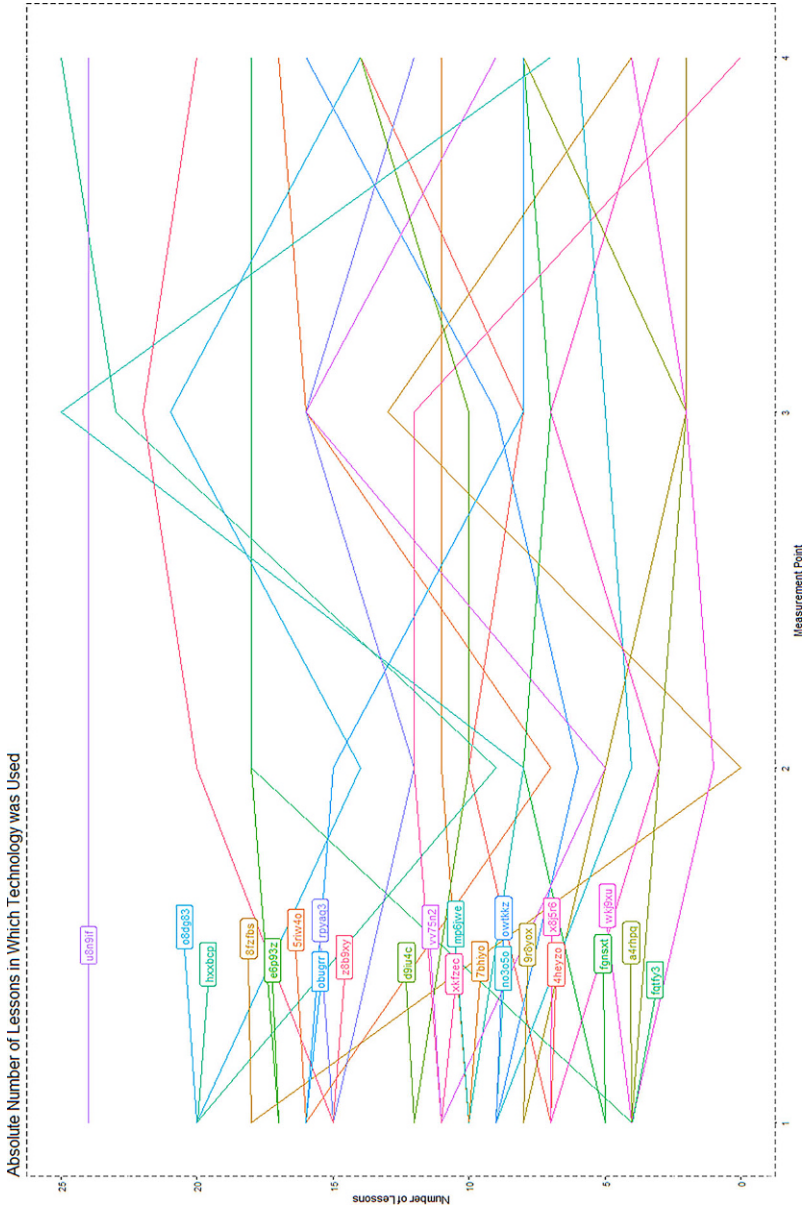


Fig. B.1 Absolute Number of Lessons in Which Technology was Used Each Week. (N = 23). Each line represents the trajectory of one teacher)

Funding This research was funded by the Federal Ministry of Education and Research (BMBF) and the Baden-Württemberg Ministry of Science as part of the Excellence Strategy of the German federal and state governments. This research was supported by the Postdoctoral Academy of Education Sciences and Psychology of the Hector Research Institute of Education Sciences and Psychology, Tübingen, funded by the Baden-Württemberg Ministry of Science, Research, and the Arts.

Funding Open Access funding enabled and organized by Projekt DEAL.

Declarations

Conflict of interest T. Fütterer, I. Backfisch and A. Lachner declare that they have no competing interests.

Ethical standards An ethics committee approved the study and the collection of the data and confirmed that the procedures were in line with ethical standards of research with human subjects (date of approval: 03/12/2020, file number: AZ.: A2.5.4-148_ns). In addition, the study was approved by the Ministry of Education, Youth, and Sports Baden Württemberg.

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