Research paper

Changes in early career teachers' technology use for teaching: The roles of teacher self-efficacy, ICT literacy, and experience during COVID-19 school closure

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ABSTRACT

This study examines how early-career teachers' experience and perceived support during the pandemic affected their technology integration self-efficacy and their use of information and communication technology (ICT) after school closure. The results reveal that teachers' positive teaching experiences were associated with their technology integration self-efficacy and their self-reported changes in technology use after the school closure. The results show effects of ICT literacy and general teacher self-efficacy on technology integration self-efficacy. ICT literacy, teacher self-efficacy, and positive experience had indirect effects, whereas support and technology integration self-efficacy had direct effects on changes in teachers' ICT use for teaching.

1. Introduction

As a means of reducing interpersonal contact during the COVID-19 pandemic, many nations temporarily closed educational institutions and introduced distance learning in most schools worldwide between March and April 2020 (UNESCO Institute for Statistics, 2020). This regulation has had a profound impact, with classroom instruction replaced by various versions of distance education often based on the use of information and communication technology (ICT). The pandemic has revealed the importance of technology in learning and teaching and has resulted in the expanded use of online teaching (Adedoyin & Soykan, 2020). The transformation of teaching and learning environments has generated significant difficulties throughout the education field. The need for distance education during the pandemic compelled school administrators to provide technology and pushed teachers to adapt to new forms of remote instruction to ensure students' ongoing access to learning (Burke et al., 2023; König et al., 2020; Vidergor, 2023).

Although the transition to remote education and the use of ICT for teaching was enforced due to COVID-19, technology-enabled change in education had been around for a while. The development of ICT innovations has led to the creation of various educational applications that offer students an engaging and hands-on learning experience (de Koning-Veenstra et al., 2014; Hwang et al., 2015; Koong & Wu, 2011). In recent years, considerable attention has been paid to the benefits that ICT can bring to learning and teaching in schools. Empirical findings revealed that incorporating technology in the classroom can greatly enhance learning outcomes (Chauhan, 2017; Zhu & Urhahne, 2018), making digital teaching skills and ICT proficiency essential competencies for educators even before the pandemic-related school closures (Koehler & Mishra, 2009; Martin, 2015; Tondeur et al., 2012). In particular, teachers should be able to integrate technology into their pedagogical approaches and apply it in classroom practice with learning objectives in mind (König et al., 2022; Mishra & Koehler, 2006). However, the survey results in Germany show that, on average, teachers rarely use technology in the classroom and exploit its potential only to a limited extent (Autorengruppe Bildungsberichterstattung, 2020; Fraillon et al., 2019).

From this perspective, the recent experiences with pandemic distance education and the major changes in teaching might have provided teachers with opportunities to expand their range of digital skills, and adopting technology in educational settings might come with positive effects on their ICT integration into classroom instruction (Chou & Chou, 2021; Hershkovitz et al., 2023; Khong et al., 2022). In particular, young recently graduated teachers who have been exposed to technology and computers from an early age on and who view digital media as an integral part of their lives should have been able to adapt quickly to the

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challenges of online teaching and benefit from their experiences in the long run (König et al., 2020).

To investigate the impact of distance learning that was necessitated by the pandemic on post-pandemic education, this study examines how early-career teachers' experience and perceived support during the first school closure affected their technology integration self-efficacy and their use of digital learning materials for teaching in classroom instruction after school closure. Using data from a nationwide longitudinal panel study, the effects of early-career teachers' pre-pandemic personal resources—i.e., ICT literacy and (general) teacher self-efficacy—are taken into account.

1.1. Online teaching during COVID-19 school closure

The school closures confronted teachers with a completely new teaching situation (Burke et al., 2023; Huber & Helm, 2020). In numerous cases teachers lacked knowledge about how to perform and support online learning, as it is not included in many teacher education programs (Eickelmann & Gerick, 2020; McAllister & Graham, 2016). Thus, they had to switch to distance education without preparation, which in turn made it necessary to utilize a variety of digital tools (Eickelmann & Gerick, 2020). The school barometer surveyed students, teachers and parents in Austria, Germany and Switzerland during school closure. The results show that a variety of distance teaching practices were reported by study participants (e.g., Huber & Helm, 2020). Helm et al. (2021) present a systematic review on teaching and learning characteristics during the pandemic school closures. The review includes 97 online surveys that interviewed a total of 255,955 people (students, parents, teachers, principals, etc.) in 2020. The results reveal, that most teachers shared digital learning materials with students via email, learning platforms, cell phones, or video conferences (Helm, et al., 2021; see also Huebener et al., 2020). Another task teachers had was to keep in contact with their students to promote social integration. However, survey results show, that many of the students rated the contact with their teachers during distance learning as inadequate (Helm et al., 2021). An et al. (2021) examined the experiences of K-12 teachers during the COVID-19 pandemic in the United States with a mixed-method study. The survey was completed by 107 teachers from 25 states in the US, while the interviews involved 13 teachers from 10 different states. Similar to the results from Helm et al. (2021), they found in the interviews a great variety in distance teaching practices (e.g. video lectures, reading materials, online discussions) and they identified a lack of student participation and teacher–student interaction as a challenge. In addition, Pozo et al. (2021) investigated the activities of 1403 teachers in primary and secondary education from Spain during school closure. The survey results reflect that the participants used reproductive learning activities more often than constructive learning activities ($\eta^2 = 0.61$). Additionally, they conducted a cluster analysis and identified four teaching profiles depending on the frequency and type of ICT use (Passive, Active, Reproductive, Interpretative). In that study, previous use of ICT was a relevant predictor for the frequency of different activities, resulting in an over-representation of teachers who had previously used educational technology in the interpretative profile (Pozo et al., 2021).

Given the high challenges for teachers during school closure (Adedoyin & Soykan, 2020; Burke et al., 2023), the quality of teaching might have depended on the dispositions and skills of individual teachers and on contextual factors such as high-quality support. Specifically, the extent and quality of using technically supported distance teaching might be determined by teachers' readiness for distance teaching, which requires not only technological and pedagogical (content) knowledge on how to support learning online but also online teaching self-efficacy and institutional support for the implementation of online education (Backfisch, Scherer, et al., 2021; Hershkowitz et al., 2023; Howard et al., 2021; Scherer et al., 2021; Scherer et al., 2023). The latest research findings corroborate this assumption. Pozo et al. (2021) found previous

use of ICT to be a significant predictor of distance teaching activities. Hong et al. (2021) examined 1568 Chinese preschool teachers during COVID-19. Results of structural equation modelling (SEM) revealed that preschool teachers' computer self-efficacy ($\beta = 0.32$) and perceptions of external control ($\beta = 0.65$; e.g., availability of resources) were positively associated with perceived ease of usage of the educational technology. Börnert-Ringleb et al. (2021) explored 722 special-education teachers' use of digital learning and teaching during the first school closure, and their results indicated positive impacts of school-principal support ($\beta = 0.25$) and teachers' digital learning self-efficacy ($\beta = 0.16$) on the frequency of special-education teachers' use of digital learning. Vidergor (2023) found teachers' digital learning self-efficacy ($\beta = 0.47$) and teachers innovativeness ($\beta = 0.48$) to be a significant predictors of distance teaching practice among 200 Israeli teachers. König et al. (2020) investigated 165 early-career teachers' mastery of core challenges during COVID-19 school-closure teaching and discovered that teachers' proficiency in using ICT and the opportunities available for them to enhance their skills favored the adoption of online instruction in terms of maintaining social contact, providing task differences and introducing new learning content with small effect sizes.

1.2. Use of ICT for teaching and learning

Given the growing digitalization across various domains, using ICT for teaching is necessary for two reasons. Firstly, it helps students enhance their digital literacy and prepares them for active participation in 21st-century societies. Secondly, it improves the teaching and learning processes by leveraging digital technology (OECD, 2015). Subsequently, the focus is on how digital media can be used to facilitate and improve the achievement of educational goals. The integration of technology in education presents numerous possibilities to enhance the quality of instruction and improve learning outcomes (Hwang et al., 2015; Koong & Wu, 2011). Recent research shows that the incorporating of technology into educational instruction in a meaningful way can enhance learning outcomes (Chauhan, 2017; Hillmayr et al., 2020; Zhu & Urhahne, 2018). Results from recent meta-analyses reveal significant effects for different subjects and learning environments (Chauhan, 2017; Hillmayr et al., 2020).

Teachers face the challenge of integrating digital media into complex classroom instruction in a way that adds value; ensuring it supports education goals and does not become a distraction. While educators commonly use ICT applications in their personal lives, employing technology in educational settings appears to be more precarious. This also applies to young teachers who grew up using many different digital tools in their daily lives and who are skilled in using technology for communication, entertainment, and information (Lei, 2009; Sailer et al., 2021; Valtonen et al., 2011). Although teachers are well-acquainted with different ICT applications, their competence in utilizing them for educational objectives is limited (Lei, 2009; Tondeur et al., 2012; Valtonen et al., 2011). An explanation for the difficulties which educators face in integrating digital media into their teaching practices is that they may lack adequate personal experience in creating digital learning spaces (Lei, 2009; Valtonen et al., 2015).

1.3. Factors explaining teachers' use of ICT

Recent research has identified several relevant conditions that can explain teachers' use of technology; especially noteworthy are the accessibility of technological infrastructure (Drossel et al., 2017; Fraillon et al., 2014; Petko, 2012), teachers' ICT literacy (MacCallum et al., 2014), and teachers' professional knowledge (Mishra & Koehler, 2006). Particular emphasis has been placed on the importance of teacher motivation as another facilitating factor of technology integration (e.g., Backfisch, Scherer, et al., 2021; Ifenthaler & Schweinbenz, 2013; Petko, 2012; Scherer et al., 2019; Scherer & Teo, 2019; Teo, 2011; Vongkulluksn et al., 2018).

Developed originally for the industrial context (Davis, 1989), the technology acceptance model (TAM) explains the factors that influence educators' motivation to accept and adopt technology (Scherer et al., 2019; Scherer & Teo, 2019; Teo, 2011; Wong, 2016). According to TAM, the behavioral intention to use ICT for teaching depends on attitudes toward the technology, which in turn are influenced by its perceived ease of use (PEU) and perceived usefulness (PU). PU pertains to how much a technology can enhance a user's capabilities, whereas PEU point to the level of effort needed to use the technology effectively (Davis, 1986). TAM has been used frequently to describe teachers' integration of technology into their practice. In a meta-analysis of 45 studies, Scherer and Teo (2019) showed that TAM variables explain 39.2% of the variance in teachers' intentions to use ICT for teaching; the results revealed that teachers are more likely to use ICT for teaching if they perceive it as easy to use and useful. Specifically, PU was consistently related to usage intentions and—unlike in the original TAM model—showed not only indirect effects (mediated by teachers' attitudes) but also direct effects on behavioral intentions. It is concluded that interventions aimed at increasing teachers' intentions to use ICT for teaching should particularly support teachers in perceiving technology as useful for teaching and learning (Scherer et al., 2019; Scherer & Teo, 2019).

In addition, TAM has often been extended to include other (external) variables that can predict PEU and PU, e.g., perceptions of how important others assess the use of ICT, technology-related self-efficacy, and facilitating conditions such as organizational resources and support (Scherer et al., 2019). Scherer et al. (2019) conducted a meta-analysis based on 114 empirical TAM studies (N = 34,357 teachers) and demonstrated the fit of the TAM. Specifically, they showed that the external variables of subjective norms, computer self-efficacy, and facilitating conditions affect both, PEU and PU to varying degrees. The strongest predictors of PU were subjective norm ($\beta = 0.28$) and computer-self-efficacy ($\beta = 0.23 - 0.24$) and of PEU facilitating conditions ($\beta = 0.30$) and computer-self-efficacy ($\beta = 0.37–39$). Moreover, the meta-analytic results showed that stronger behavioral intentions led to higher degrees of technology integration.

A key research finding is that two main components of teacher motivation to integrate technology into classroom practice represent the main barrier to the realization of technology-based instruction: technology-related self-efficacy beliefs and utility value of teaching with ICT (Backfisch, Lachner, et al., 2021; Joo et al., 2018; Teo & Tan, 2012). According to Bandura's self-efficacy theory (Bandura, 1986), individuals' beliefs in their own capabilities are shaped by previous experiences with technology, meaning those who have had meaningful and positive experiences are more likely to perceive themselves as capable of applying technology. Thus, developing strong intentions to use technology in the classroom seems to be strongly linked to having a meaningful and positive experience using it and, thus, demonstrating its benefits (Joo et al., 2018; Scherer et al., 2019; Scherer & Teo, 2019). This supposition is consistent with the findings of Valtonen et al. (2015), who revealed that learning in genuine ICT learning settings had a favorable effect on student teachers' subjective norms regarding technology and their development of self-efficacy.

While TAM is effective in elucidating teachers' acceptance of technology, it has constraints in its ability to conceptualize how technology can be incorporated into classroom instruction (Scherer et al., 2019). Specifically, the model does not specify the digital skills and professional knowledge that teachers require to integrate technology meaningfully in their classroom. General digital skills that are considered significant for participation in work life and society are described in the current models of ICT literacy (Siddiq et al., 2016). ICT literacy can be defined as "the interest, attitude, and ability of individuals to appropriately use digital technology and communication tools to access, manage, integrate, and evaluate information; construct new knowledge; and communicate with others in order to participate effectively in society" (Lennon et al., 2003, p. 8).

One prominent model that describes the required professional knowledge of teachers for successful digital technology integration is TPACK (Technological Pedagogical Content Knowledge) (Chai et al., 2013; Koehler & Mishra, 2009; Mishra & Koehler, 2006; Voogt et al., 2013). TPACK defines different kinds of intertwining and interacting knowledge domains: content knowledge, pedagogical knowledge, technology knowledge, pedagogical content knowledge, technological content knowledge, technological pedagogical knowledge, and technological pedagogical content knowledge (Mishra & Koehler, 2006).

Numerous investigations have found positive relationships among self-reported TPACK and self-reported frequency (e.g., Chuang et al., 2015; Habibi et al., 2019; Jang & Tsai, 2012; Jung et al., 2019; Li et al., 2019) or self-reported quality of technology use in classroom instruction (Kabakci Yurdakul & Çoklar, 2014). A finding in the study of MacCallum et al. (2014) was the positive association between ICT literacy and intentions to adopt mobile learning. Furthermore, research has confirmed that self-reported TPACK is positively related to ICT-integration self-efficacy (e.g., Hsu et al., 2017; Joo et al., 2018; Kaşcı & Selçuk, 2021; Sahin et al., 2013; Semiz & Ince, 2012) as well as to PEU and PU (e.g., Joo et al., 2018). In their meta-analysis, which based on 28 studies (N = 7777), Zeng et al. (2022) found a positive association between teachers' self-reported TPACK and information-technology integration self-efficacy ($r = 0.61$), which was moderated by the teachers' career stages; specifically, they found a substantial higher relationship among pre-service teachers ($r = 0.67$) compared to in-service teachers ($r = 0.54$), and they explained this moderating effect with differences in the ICT-related cognitions and actions between the two groups.

1.4. Post-pandemic use of ICT

The transition to remote learning that was required as a result of COVID-19-related school closures put teachers in a demanding situation: they quickly had to adopt forms of technology-based teaching and communication that were new to them in the required extent. Given the need for technology-enhanced instruction during the pandemic, the question is whether teachers took away anything positive from this experience for using ICT in the post-pandemic classroom. To this date, only a few available studies have examined teachers' intentions for post-pandemic technology-based instruction. Khong et al. (2022) investigated 1740 Vietnamese secondary school teachers using a large-scale cross-sectional survey. The SEM results revealed significant effects of self-reported TPACK ($\beta = 0.26$), PU ($\beta = 0.33$), training and support ($\beta = 0.14$), on the intention of secondary school teachers to teach online post-pandemic. Chou and Chou (2021) examined 488 Taiwanese teachers who served in primary, secondary or higher education. Results from multigroup analysis showed that the intention of Taiwanese secondary education teachers to continue teaching online was related to their online teaching experience before the pandemic ($\beta = 0.19$), technostress ($\beta = -0.18$), online-teaching self-efficacy ($\beta = 0.38$), and school support ($\beta = 0.18$). The intention of primary education teachers to continue teaching online was only related to their technostress ($\beta = -0.34$), and online-teaching self-efficacy ($\beta = 0.30$). However, the existing studies are limited, because they investigated intentions to teach online post-pandemic and offer no conclusions about ICT integration in the post-pandemic classroom.

1.5. The present study

The main aim of the study reported herein was to investigate the factors involved in changes in early-career teachers' use of ICT for teaching and learning after the first pandemic school closure. The study examined how teachers' experiences of digital-enhanced teaching during the initial school closure, their technology integration self-efficacy, and self-reported changes in their use of ICT for teaching and learning after school closure were related to each other. Also, the role of pre-pandemic personal resources (ICT literacy and general teacher self-efficacy) was an area of investigation in this context. Fig. 1 illustrates the theoretical model. Based on (1) research within the TAM framework,
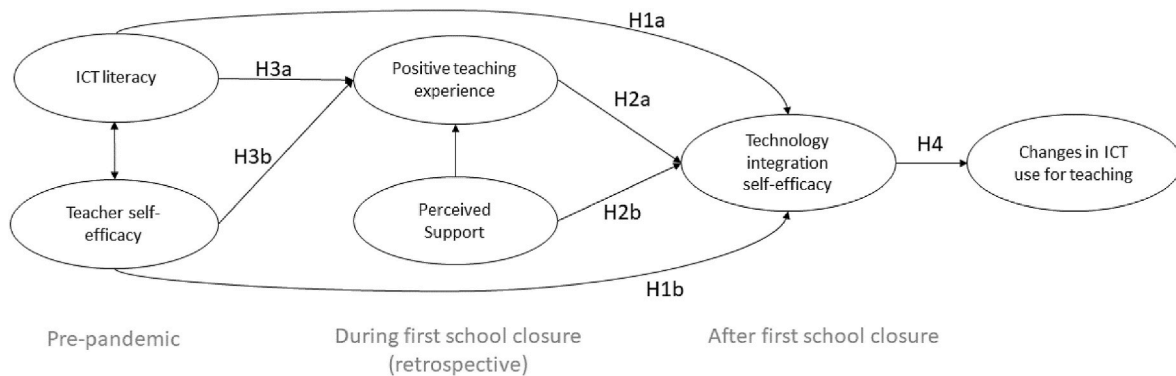
Fig. 1. Theoretical model and hypotheses.

which demonstrated the relevance of technology-related self-efficacy and facilitating conditions for ICT integration (e.g. Scherer et al., 2019) and (2) research showing the impact of TPACK resp. ICT literacy for technology use in classroom (e.g., Chuang et al., 2015) and (3) research about factors influencing pandemic distance teaching demonstrating the role of teachers' readiness (e.g. Pozo et al., 2021; Vidergor, 2023), we propose the hypotheses as following:

H1. Pre-pandemic teacher self-efficacy (H1a) and ICT literacy (H1b) predict technology integration self-efficacy (after first school closure).

H2. Positive experiences with distance education (H2a) and perceived support (H2b) during school closure predict technology integration self-efficacy (after first school closure).

H3. Pre-pandemic teacher self-efficacy (H3a) and ICT literacy (H3b) predict positive experiences with distance education.

H4. Technology integration self-efficacy after the initial school closure predicts self-reported changes in teachers' use of ICT for teaching and learning after school closure.

H5. Pre-pandemic teacher self-efficacy (H5a), ICT literacy (H5b), positive experiences with distance education (H5c), and perceived support during school closure (H5d) have indirect effects on self-reported changes in teachers' use of ICT for teaching and learning after school closure mediated by technology integration self-efficacy (after first school closure).

2. Methods

2.1. Sample

Data were drawn from the National Educational Panel Study (NEPS): Starting Cohort First-Year Students, which is an add-on study of the first-year student cohort of NEPS (https://doi.org/10.5157/NEPS:SC5 :17.0.0; Blossfeld & Roßbach, 2019), a nationwide random sample that aims to depict educational pathways through the life course in Germany. The participants entered higher education in the winter term of 2010/11. Students in a teacher education program were over-sampled, resulting in a larger sample size (Schaeper et al., 2023). In the 17th survey wave conducted between November and December 2020 (after first school closure), (retrospective) questions about the situation of teachers during the COVID-19 pandemic were implemented.

In total, 965 early-career teachers (75% female, 25% male) were teaching during the second half of the 2019/2020 school year when the first school closure took place in Germany. The majority of the participating in-service teachers began their university teacher training nine years before (see above). In Germany, the standard period of university teacher training is approximately 4–5 years, followed by a 12–18 month preparatory service. The maximum duration working as an in-service teacher is therefore 4 years. The participants' average age was 30.25

years (SD = 2.33) at the beginning of the school closures (March 2020), which indicates that the teachers were in the early stage of their professional career. Among the participants, 20% worked in elementary schools, 14% in secondary/middle schools, 33% in high schools/gymnasia, 12% in comprehensive schools (*Gesamtschule*), 8% in special schools, and 9% in vocational schools. About 3% either worked in different schools or did not answer this question. Most of them (28%) taught students in grades 8–10, 24% taught grades 1–4, 22% taught grades 5–7, 18% taught grades 11–13, and 8% said that no classification in class levels was possible.

Early-career teachers were asked to describe their actions during the initial period of distance learning through the following inquiry: *How did you provide learning materials for your students during the first few months of school closures?* The findings showed that 77% of the participating early-career teachers offered their students digital learning materials via online platforms, online courses, or digital classrooms/school clouds, 45% via virtual conferences or video chats (e.g., Skype or other providers), 73% via e-mails, 17% via short message services such as SMS, WhatsApp, Threema, etc., 37% via phone contact with students or their parents, 19% via letters or other mail, 24% in printed form for picking up, and 4% in other ways.

2.2. Measures

To take the shift to online or remote learning into account, novel scales were designed, and a description of each research tool is provided below. All items were presented in German. An overview of all items translated in English is provided in supplement 1. Confirmatory factor analyses (CFAs) were carried out to test the fit of the measurement model to observed data.

2.2.1. Self-reported changes in teachers' use of ICT for teaching and learning

To assess the subjects' use of ICT for teaching and learning after school closure, a scale consisting of four items was newly designed (inspired by Bos et al., 2010). The period prior to the adoption of distance learning was established as a reference point, as follows: *Now, thinking about the time when schools reopened and about your classes, do you use digital media in face-to-face classes for the following purposes less (=1), as frequently as before (=2), or more (=3) compared to the time before the corona crisis?* The internal consistency of the scale was $\alpha = 0.67$. The indicators used in this scale are ordinal in nature, and during the analyses, this characteristic is considered.

2.2.2. Technology integration self-efficacy

The second scale, adapted from Dinse de Salas (2019), Bosse and Spörer (2014), and Schaeper and Weiß (2016), comprising five items designed to assess technology integration self-efficacy (e.g., *I have the confidence to design lessons with digital media so that students use learning*

time effectively). Participants were requested to rate the degree to which the statements applied to them, using a six-point Likert scale (1 = does not apply at all; 6 = applies completely). Item 4 was removed from the scale, as it showed a factor loading <0.4 (Stevens, 1992) in the CFA (see below). The internal consistency of the resulting scale was $\alpha = 0.82$.

2.2.3. Teachers' positive experience with distance education

To assess teachers' positive experience with distance education, a scale consisting of three items was newly designed (e.g., *During the school closure it was easy for me to provide learning materials for homeschooling*). Participants were requested to indicate their level of agreement using a four-point Likert scale (1 = very strongly disagree; 4 = very strongly agree). The internal consistency of the scale was $\alpha = 0.58$.

2.2.4. Perceived support during school closure

The perceived support during school closure was assessed with two items: *During the school closure, 1) the colleagues supported each other very well, and 2) my principal was an important support for me.* Participants were requested to indicate their level of agreement using a four-point Likert scale (1 = very strongly disagree; 4 = very strongly agree). The correlation of the two items was $r = 0.44$.

2.2.5. Teacher self-efficacy (TSE)

TSE was measured using the ten-item scale by Schwarzer and Schmitz (1999). The assessment of TSE took place between March and August 2019 (wave 15), which was about nine years after most of the participants began their initial teacher education and about one year before the pandemic started. About 72% of the participants were already working as teachers by that time, 9% were in the preparatory phase, 2% were between the preparatory phase and work entry, and 17% had an unknown status, because they did not participate in wave 15. Participants were requested to indicate their level of agreement using a four-point Likert scale (1 = very strongly disagree; 4 = very strongly agree). Items 6 and 8 were removed from the scale due to the factor loadings being <0.4 (Stevens, 1992) in the CFA (see below). The internal consistency of the resulting scale was $\alpha = 0.71$.

2.2.6. ICT literacy

ICT literacy was evaluated using 36 multiple-choice items. The measurement of ICT literacy took place between May and July 2013 (wave 5) and therefore about three years after the participants began their initial teacher education and seven years before the pandemic started. Thus, the participants were all still in university education. The assessment was founded on the ETS (2002) definition of ICT literacy and was operationalized using components of technology and information

literacy [accessing, creating, managing, and evaluating information; see Senkbeil et al. (2019) for details]. Participants had to deal with realistic problems embedded in a range of authentic situations. Most items used screen-shots as prompts, and each item required a multiple-choice response (Senkbeil et al., 2019). The test was scaled based on item response theory (IRT) (Fischer et al., 2016; Pohl & Carstensen, 2013), Proficiency scores were computed as weighted maximum-likelihood estimates, and the test's internal consistency, as determined by IRT, was 0.72 [EAP/PV reliability; see Senkbeil et al. (2019)].

2.3. Data analysis

IBM SPSS Statistics 28.0 (IBM Corp., 2017) and Mplus 8.7 (Muthén & Muthén, 2012) were employed for data analysis. The proportion of missing values ranged from 0.1% to 21.7% (see Table 1). The highest proportion of missing values are found on variables from wave 5 (ICT literacy) and wave 15 (TSE). The missing values occur mainly due to the study design, as not every student received a competence test, and also because participants did not take part in every survey wave (unit non-response). The proportions of missing values on single variables from wave 17 were very low, ranging between 0.1% and 4.0% (item non-response). The Little's Missing Completely at Random (MCAR) test was conducted to assess the missing data pattern. The chi-square calculated for the test was 458.83 ($df = 332$; $p < 0.001$), indicating that there are significant departures from the assumption of MCAR in the data. As described earlier, the missing values on the pre-pandemic variables could be explained by features of the panel study. Therefore, we assume that the data are Missing at Random (MAR). In order to account for the missing data, we employed the Full Information Maximum Likelihood (FIML) method. In addition, a supplemental model without the variables from wave 5 and wave 15 was calculated to corroborate the results (see supplement 2). Robust maximum likelihood (MLR) estimation was applied for the Likert scales used in the measurements. Weighted least squares with mean and variance adjustment (WLSMV) was used as the estimator for ordinal observed indicators. Statistical significance was assessed at the 0.05 level. Construct validity was examined using CFAs, and three models were created for the latent constructs. The exception was ICT literacy, for which weighted maximum likelihood estimates were used (WLEs).

The items from the various scales served as indicators for the latent variables. A formative measurement model was used for the latent variable *perceived support during school closure* (Bollen & Bauldry, 2011; Jarvis et al., 2003). A formative conceptualization of support proposes that perceived support causes the latent support factor. Reflective models treat the indicators as a result or consequence of the underlying

Table 1
Descriptive results, correlations, and reliability coefficients.

	1	2	3	4	5	6	7
1. Changes in ICT use for teaching [a]							
2. Technology integration self-efficacy	0.17**						
3. ICT literacy (WLEs)	0.06	0.11**					
4. Teacher self-efficacy	0.04	0.29**	−0.09[c]				
5. Positive teaching experience	0.06	0.38**	0.03	0.17**			
6. Perceived collegial support	0.12**	0.13**	−0.05	0.11**	0.22**		
7. Perceived principal support	0.09**	0.10[c]	<0.01	0.06	0.24**	0.44**	
M (Md)	(2.00) [b]	4.27	−0.05	3.14	2.38	2.73	2.36
SD	–	0.77	0.66	0.33	0.57	0.86	0.93
Min	1.00	1.00	−2.02	2.25	1.00	1.00	1.00
Max	3.00	6.00	1.96	4.00	4.00	4.00	4.00
Cronbach's alpha (EAP/PV reliability)	0.67 [a]	0.82	(0.72)	0.71	0.58	–	–
McDonald's omega (model-based)	0.68 [a]	0.82	–	0.71	0.58	–	–
N	926	964	756	787	961	963	961
Missing values	39	1	209	178	4	2	4

[a] Ordinal indicators.
[b] Each of the 4 categorical items had the same median.
[c] p < 0.05; **p < 0.01.

latent factor, while formative models treat the indicators as the source or cause of the underlying latent factor (Bollen & Bauldry, 2011).

SEM was utilized to examine the connections within the theoretical model. Furthermore, indirect effects on changes in teachers' use of ICT for teaching and learning were examined by disassembling the total effect into direct and indirect effects.

To evaluate the fit of the model, the χ^2/df test (<5), the root mean square error of approximation (RMSEA), the comparative fit index (CFI), the Tucker–Lewis index (TLI), and the standardized root mean square residual (SRMR) were used. Established threshold values for TLI and CFI were set at above 0.95 or 0.90, for RMSEA below 0.06 or 0.08, and for SRMR below 0.08 to indicate excellent and acceptable model fits.

3. Results

3.1. Descriptive results and confirmatory factor analyses

Table 1 displays the descriptive findings, correlations, and reliability estimates for the constructs. The median for each of the four categorical items of ICT use for teaching ($Md = 2$) indicated that teachers' self-reported ICT use after school closure was mostly the same as before (1 = less, 2 = equally, 3 = more).

Pre-pandemic TSE ($M = 3.14$, $SD = 0.33$), perceived collegial support during school closure ($M = 2.73$, $SD = 0.86$) and post-pandemic technology integration self-efficacy ($M = 4.27$, $SD = 0.77$) exceeded the midpoint of a four-point res. six-point scale, indicating that teachers on average expressed agreement/confidence. However, the mean scores for positive teaching experience ($M = 2.38$, $SD = 0.57$) and perceived principal support during school closure ($M = 2.36$, $SD = 0.93$), were less than the midpoint value, which suggests a lesser degree of agreement/confidence in these domains.

Furthermore, to validate the underlying structures of the latent variables, three distinct confirmatory factor analyses (CFAs) were conducted. The first one-factor CFA model consist of four ordinal indicators measuring changes in teachers' ICT use for teaching using the WLSMV estimator; the indices suggested a good model fit ($\chi^2 = 4.15$, $df = 2$, $p < 0.13$, RMSEA = 0.03, SRMR = 0.01, TLI = 0.99, and CFI = 0.99) with factor loadings between 0.57 and 0.81 (Table 2). The second two-factor CFA model consist of 15 indicators measuring technology integration self-efficacy and TSE using the MLR estimator; the model showed a good

Table 2
Factor loadings for the CFA models.

CFA model	Latent variable	Item	Factor loading
Model 1	Changes in ICT use for teaching	1	0.65
		2	0.68
		3	0.81
		4	0.57
Model 2	Teacher self-efficacy [a]	1	0.43
		2	0.51
		3	0.53
		4	0.57
		5	0.47
		7	0.39
		9	0.45
		10	0.47
	Technology integration self-efficacy	1	0.81
		2	0.78
		3	0.74
		5	0.59
Model 3	Positive teaching experience	1	0.58
		2	0.66
		3	0.47

[a] As the modification indices indicated a relation between the errors of items 9 and 10 on the Technology Self-Efficacy (TSE) scale, error correlation was permitted. These items were more alike to each other than to the other items on the scale. Items 9 and 10 both address the capability to introduce new ideas that can improve the learning experience for students (see supplement 1).

model fit ($\chi^2 = 177.19$, $df = 87$, $p < 0.001$, RMSEA = 0.03, SRMR = 0.04, TLI = 0.95, and CFI = 0.96). However, item 4 from the technology integration self-efficacy scale and items 5 and 7 from the TSE scale showed factor loadings <0.4. These items were removed from the model; the adapted model showed a good model fit ($\chi^2 = 104.54$, $df = 52$, $p < 0.001$, RMSEA = 0.03, SRMR = 0.04, TLI = 0.96, and CFI = 0.97). The factor loadings were between 0.39 and 0.81. The third one-factor CFA model consisted of three items assessing positive teaching experience using the MLR estimator and revealed a good fit to the data ($\chi^2 = 1.76$, $df = 1$, $p = 0.19$, RMSEA = 0.03, SRMR = 0.01, TLI = 0.99, and CFI = 0.99). The factor loadings were between 0.46 and 0.66.

Furthermore, a formative measurement model was used for the latent variable support. The formative model was conducted with the latent dependent variable *positive teaching experience* using the MLR estimator. The indices for this model demonstrated a good fit to the data ($\chi^2 = 12.81$, $df = 4$, $p < 0.001$, RMSEA = 0.05, SRMR = 0.02, TLI = 0.94, and CFI = 0.97) with standardized β coefficients between 0.35 and 0.61.

3.2. Results of structural equation modeling

To examine the direct and indirect relationships among self-reported changes in ICT use for teaching, technology integration self-efficacy after school closure, positive teaching experience, perceived support during school closure, pre-pandemic ICT literacy, and TSE, a structural model was tested (see Fig. 2). The results revealed a modification index of 40.90 for the direct effect from TSE to collegial support, and this effect was estimated to improve the model fit (see Fig. 2). This association means, individuals who have high self-efficacy, perceive greater support among the college. This finding is plausible, because individuals with high self-efficacy tend to have a positive outlook on their abilities and believe they can effectively accomplish tasks or overcome challenges. As a result, they are more likely to seek out and perceive support (Bandura, 1986). There was an excellent model fit ($\chi^2 = 353.51$, $df = 195$, $\chi^2/df = 1.81$, RMSEA = 0.03 [0.024, 0.034], SRMR = 0.04, TLI = 0.95, and CFI = 0.96).

The findings reveal that technology integration self-efficacy after school closure was predicted by pre-pandemic TSE ($\beta = 0.27$, $p < 0.01$), pre-pandemic ICT literacy ($\beta = 0.12$, $p < 0.01$), and positive teaching experience during school closure ($\beta = 0.47$, $p < 0.01$; see Fig. 2). Contrary to our expectations, perceived support was not a significant predictor. Therefore, these results support hypotheses 1a, 1 b, and 2a.

Pre-pandemic ICT literacy had no direct effect on positive teaching experience during school closure. However, pre-pandemic TSE was a significant predictor of positive teaching experiences ($\beta = 0.26$, $p < 0.01$). Therefore, only hypothesis 3 b can be confirmed.

As expected, changes in teachers' ICT use for teaching were predicted by technology integration self-efficacy ($\beta = 0.28$, $p < 0.01$). Therefore, this result supports hypothesis 4. Surprisingly, perceived support also had a direct effect on changes in teachers' ICT use for teaching ($\beta = 0.15$, $p < 0.01$). Furthermore, there was a negative correlation between ICT literacy and TSE ($\beta = -0.12$, $p = 0.01$).

To confirm the direct and indirect relationships among the variables from wave 17 (see 2.3), a structural model without the pre-pandemic variables was tested. The effects were almost identical (see supplement 2); the association between technology integration self-efficacy after school closure and positive teaching experience during school closure was slightly higher ($\beta = 0.56$, $p < 0.01$).
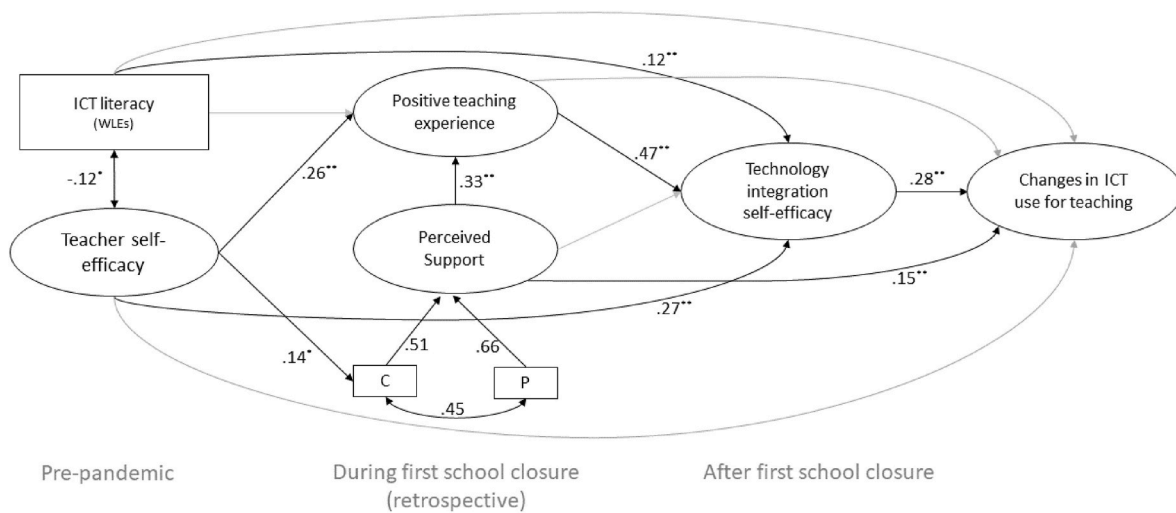
3.3. Indirect effects on ICT use for teaching

Mplus' *model indirect* feature was employed to determine both direct and indirect effects on changes in teachers' ICT use for teaching. Every specific indirect effect was computed, and the Sobel test was conducted. The results (Table 3) show that ICT literacy ($z = 0.04$, $p = 0.01$), TSE ($z = 0.09$, $p < 0.01$), and positive experience ($z = 0.13$, $p < 0.01$) had significant indirect effects on changes in teachers' ICT use for teaching

Fig. 2. Structural equation model. The figure exhibits all the paths. Not significant path displayed in grey. Direct and indirect effects among variables are shown in Table 3. Perceived support is modeled as formative latent factor; C = colleagues, P = principal. *$p < 0.05$; **$p < 0.01$.

(hypothesis 5). Among all predictors, only support had no indirect but a significant direct effect on changes in teachers' ICT use for teaching (see Fig. 2). Therefore, hypotheses 5a, 5 b, and 5c are supported.

4. Discussion

During the COVID-19 pandemic, teachers had to switch to online or remote teaching and learning as a response to school closures. This situation offered a learning experience for teachers, highlighting the need for flexible and adaptable teaching and learning practices. The present study aimed to explore early-career teachers' experience in the course of the pandemic and to reveal which factors predict teachers' ICT use for teaching right after school closure. In Germany, the use of digital media for teaching and learning in schools was not very widespread before the pandemic outbreak (Fraillon et al., 2019). Also, the status of early-career teachers being familiar with digital technology from a young age on and more flexible and adaptable, given their limited practical experience, does not ensure that they have developed advanced digital competencies (König et al., 2020). Therefore, the quick change and implementation of online teaching has potentially allowed early-career teachers to develop a better sense of what it takes to integrate technology into the classroom and the advantages it can provide. We suppose that school closures, which necessitated a shift from in-person to online learning, provided early-career teachers with an opportunity to broaden their technological skills. Drawing on TAM, it is assumed that favorable and significant

encounters with educational technology promote a strong intention of usage for teaching purposes (Joo et al., 2018; Scherer et al., 2019; Scherer & Teo, 2019; Valtonen et al., 2015). Thus, positive experiences with distance education may increase the likelihood that teachers will use ICT in post-pandemic classroom teaching.

First, we investigated the associations between early-career teachers' technology integration self-efficacy (after first school closure) and (a) teachers' pre-pandemic personal resources, specifically TSE and ICT literacy, and (b) their positive teaching experience and perceived support during school closure. Second, we examined the direct and indirect effects of (a) teachers' pre-pandemic personal resources, (b) their technology integration self-efficacy (after first school closure), and (c) their positive teaching experience and perceived support during school closure on changes in teachers' ICT use for teaching.

Based on our descriptive results, we found that despite the abrupt and ill-prepared transition from in-person to digital education, early-career teachers (on average) viewed their first school closure experience positively. They perceived their colleagues as more supportive than their principals and reported using ICT in classroom teaching to the same extent or even more after the closure.

The SEM results show that technology integration self-efficacy was predicted by TSE, ICT literacy, and positive teaching experience during school closure. This means that teachers, who had more resources before the pandemic in terms of TSE and ICT literacy and those who evaluated the experience during school closure more positively reported higher

Table 3
Standardized indirect effects on changes in ICT use for teaching.

Predictor	Effect on changes in ICT use for teaching			
		Coefficient (*p*-value)	95% confidence interval [a]	
			Lower 2.5%	Upper 2.5%
ICT literacy	Direct	0.04 (0.41)	−0.05	0.15
	Indirect	0.04 (0.01)	0.01	0.07
	Total	0.08 (0.10)	0.00	0.18
TSE	Direct	−0.01 (0.84)	−0.16	0.12
	Indirect	0.09 (<0.01)	0.04	0.15
	Total	0.08 (0.21)	−0.04	0.19
Positive experience	Direct	−0.11 (0.16)	−0.25	0.04
	Indirect	0.13 (<0.01)	0.06	0.22
	Total	0.02 (0.74)	−0.10	0.16
Support	Direct	0.15 (<0.01)	0.05	0.22
	Indirect	−0.01 (0.82)	−0.06	0.05
	Total	0.14 (<0.01)	0.07	0.21

[a] 95% bias-corrected bootstrap confidence interval using 500 resamples.

technology integration self-efficacy after school closure. This result contradicts Pressley and Ha (2021), who found that previous success in the classroom did not impact teachers' instructional efficacy during pandemic distance teaching. A possible explanation for this could be that Pressley and Ha (2021) investigated general instructional efficacy whereas the focus of this study was on technology integration self-efficacy controlling for experiences and support during school closure. However, support had no direct impact on teachers' technology integration self-efficacy, but it had an effect on positive teaching experience, which implies an indirect effect on technology integration self-efficacy. This corroborates the results of Chou and Chou (2021), who found a relationship between online teaching self-efficacy and school support during the pandemic. The results of the present study parallel those of previous studies that identified ICT literacy and favorable educational technology encounters as significant elements in building domain-specific self-efficacy (Rohatgi et al., 2016; Valtonen et al., 2015).

An additional research area centered on the prediction of post-pandemic changes in ICT use for teaching. As expected, technology integration self-efficacy proved to have a statistically significant effect on changes in teachers' use of ICT in classroom teaching after school closure. In other words, the higher the technology integration self-efficacy of teachers, the more they used ICT integration compared to pre-pandemic teaching. This suggests that it is important that teachers feel competent to implement ICT in their teaching activities. This finding is consistent with other research indicating that teachers' self-efficacy is a predictor of their behavioral intentions (Joo et al., 2018; Valtonen et al., 2015; Scherer et al., 2019; Backfisch, Scherer, et al., 2021). It is also consistent with the findings of Chou and Chou (2021), who reported that online teaching self-efficacy was related to teachers' intentions to continue using online teaching.

Furthermore, the analysis of direct and indirect effects on changes in teachers' use of ICT for teaching and learning revealed that the effects of ICT literacy, TSE, and positive experience during school closure are fully mediated by technology integration self-efficacy. This finding implies that positive experiences with ICT affect teachers' actions when they see themselves as self-efficacious. This result confirms the significance of teacher motivation in incorporating technology into classroom instruction (Backfisch, Lachner, et al., 2021; Backfisch, Scherer, et al., 2021; Scherer et al., 2019) and reveals that pandemic-related experience could contribute to teachers' ICT integration in the post-pandemic classroom (cf. Paetsch & Drechsel, 2021). A direct effect on changes in teachers' use of ICT for teaching was found for perceived support, which means, that teachers who perceived higher levels of supportive behavior from their colleagues and support from their principal during the pandemic were more likely to adopt and utilize ICT tools in their post-pandemic teaching practices, regardless of their technology integration self-efficacy. This finding suggests that a supportive environment, both from peers and school leadership, plays a crucial role in facilitating teachers' willingness and ability to incorporate technology in their classrooms. The consistency of this result with the findings of Chou and Chou (2021), who found a significant relationship between school support and the intention of Taiwanese secondary education teachers to continue teaching online, further strengthens the validity of this observation and, thus, indicates that a supportive work environment could have additional impact on teachers' ICT use. Distinguishing school support into social, technical, and material support in future research has the potential to provide deeper insights into the specific aspects of support that are most influential in promoting effective technology integration among teachers (König et al., 2020; Chou & Chou, 2021). For example, exploring the role of social support in facilitating technology integration can shed light on the importance of fostering a collaborative and positive school climate, where teachers feel comfortable sharing ideas, seeking assistance, and engaging in professional dialogue related to technology use.

5. Limitations and future directions

The present study has a few limitations, one being that the validation of the recently created measurement tools was not established because of the rapidly changing situation. Retrospective self-reported changes in early-career teachers' technology use for teaching might differ from changes collected on the basis of two measurement points, and continued research is required in this regard (e.g., longitudinal studies, alternative measures). Another limitation of our study was the low reliability observed for the newly developed scale "Teachers' positive experience with distance education," which consisted of only three items. The short scale enabled an economical measurement, however, the low reliability suggests that the scale may not have accurately captured teachers' experiences. Consequently, the findings related to this specific scale should be interpreted with caution, considering its limited scope and potential measurement inconsistencies. One more constraint pertains to the reliance on self-reported measures. It is feasible that socially desirable answers from early-career teachers may have introduced bias to the data, possibly resulting in dissimilar outcomes from other methodologies, like behavioral observation. Moreover, multiple additional factors that could influence changes in early-career teachers' technology use and technology-related self-efficacy remain uninvestigated (i.e., PU of educational technologies, attitudes toward technology).

Although the data was drawn from a large-scale panel study (Blossfeld & Roßbach, 2019), a longitudinal study design measuring variables multiple times could not be applied. As such, causal inferences cannot be drawn from the results, and the identified relationships cannot be unequivocally interpreted. Bidirectional relationships and reverse causality are plausible; for instance, technology integration self-efficacy may have influenced positive experience during the pandemic. Another limitation is the use of measures collected several years before the start of the pandemic, which may have led to inaccurate estimates of ICT literacy and TSE. This fact might explain the low impact of ICT literacy in this study.

Furthermore, a relatively high proportion of missing values occurred in the pre-pandemic variables. It is important to acknowledge that the presence of missing data can potentially introduce bias and limit the generalizability of the findings. However, to mitigate this limitation, efforts were made to address missing data through appropriate statistical techniques.

Nevertheless, the outcomes of the current research furnish valuable insights into the encounters of early-career teachers during the incredibly demanding period of school closures, and offer suggestions for enhancing technology integration.

6. Conclusions and implications

Many teachers and students have experienced distance education during the pandemic, and those experiences impact post-pandemic face-to-face instruction. To date, however, few empirical results are available on this issue. Our study contributes to the literature in several ways. Firstly, it is among the very few studies, which have investigated the relationship between teachers' experience during pandemic school closure and their post-pandemic teaching using a large-scale survey design. Secondly, the results of this study highlight the role of pandemic-related experience, technology integration self-efficacy, and support for early-career teachers' ICT integration in the post-pandemic classroom. Thirdly, this study investigated early-career teachers, a population not often investigated in the current literature on ICT use for teaching.

As schools look upon a future with an expanded use of technology in teaching, teachers need to feel supported. The results of this study suggest that early-career teachers are more likely to integrate ICT in post-pandemic instruction when they receive social support from principals and colleagues. Thus, learning opportunities, which specifically address ICT integration in teacher education and professional

development need to be embedded in a supportive social context. Furthermore, our findings highlight the connection between teachers' experiences and their technology integration self-efficacy. Therefore, schools and teacher educators should consider teachers' motivation when reappraising pandemic experiences or introducing initiatives to improve the technical infrastructure in schools.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have shared the link to the data in the method section

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tate.2023.104318.

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