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The effects of formal and informal learning opportunities on teachers' ICT-related attitudes and self-efficacy

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ABSTRACT

The integration of information and communications technology (ICT) in education is increasingly emphasised, with teachers' attitudes and self-efficacy regarded as pivotal for ICT use. This study explores ICT-related attitudes and self-efficacy among 1608 teachers in Germany. It examines how formal and informal teacher professional development (TPD) activities, along with personal and school characteristics, are associated with these factors. Teachers generally display moderately positive attitudes ($M = 2.73$, $SD = 0.62$) and self-efficacy ($M = 2.73$, $SD = 0.66$) in ICT use, measured on a 4-point Likert scale. Informal learning activities significantly predicted ICT-related self-efficacy ($\beta = 0.15$), exceeding the impact of formal TPD ($\beta = 0.08$). However, neither type of TPD strongly predicts ICT-related attitudes. The study highlights the potential of combining structured training with informal learning to support ICT use. These findings inform strategies to enhance teachers' digital readiness, address individual needs, and foster engagement with technology in education.

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KEYWORDS
Digital learning; ICT integration; teacher competence; professional development programs; technology adoption

Introduction

Digital transformation requires schools to improve learning outcomes through information and communications technology (ICT) while preparing students for a digitised society (Fraillon et al. 2020). Research underscores the importance of thoughtful ICT integration to positively impact students' ICT competencies and success (Hillmayr et al. 2020).

Teachers' attitudes towards and their self-efficacy in using ICT are important for effective classroom use, yet vary significantly (Abel, Tondeur, and Sang 2022; Paetsch, Franz, and Wolter 2023). Understanding more about these factors is crucial to enhance teachers' effectiveness in ICT use but representative data is scarce.

A possible contribution to the development of ICT-related attitudes and self-efficacy may be teacher professional development (TPD) as multiple studies have established a link between TPD and the improvement of teachers' general attitudes and self-efficacy (Darling-Hammond, Hyler, and Gardner 2017). Accordingly, formal TPD programs and

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teachers' informal learning activities can be a key approach to boosting ICT-related attitudes and self-efficacy (Peng, Abdul Razak, and Hajar Halili 2024; Richter et al. 2014). However, little is known about the distinct effects of teachers' formal versus informal learning activities on ICT-related attitudes and self-efficacy.

By addressing these gaps, this study provides insights into the levels of ICT-related attitudes and self-efficacy in a representative German teacher sample and examines the predictive roles of formal and informal, as well as ICT-related professional development, alongside personal and school-related characteristics, in shaping attitudes towards and self-efficacy in ICT use.

Theoretical background

ICT integration in the classroom: attitudes and self-efficacy

The present study examines attitudes towards ICT use in the classroom, and teachers' self-efficacy in ICT use because these factors are important predictors of teachers' ICT-related behaviour (Caena and Redecker 2019). Following Ajzen's definition (Ajzen 2005), attitudes can be defined as predispositions to respond favourably or unfavourably towards the use of ICT in the classroom shaping teachers' willingness and effectiveness to integrate technology (Cabellos, Siddiq, and Scherer 2024).

Empirical studies underscore the strong relationship between positive attitudes towards ICT and its use in education (Tondeur et al. 2017). Teachers perceiving ICT as beneficial and aligned with their teaching philosophy are more inclined to integrate these tools (Teo 2008). Guggemos and Seufert (2021) found that teachers with favourable attitudes are more likely to adopt ICT in their teaching. These findings highlight that attitudes are not merely passive states but active determinants of how technology is utilised (Kreijns et al. 2013). Pozas and Letzel (2023) have shown that pre-service teachers show very favourable attitudes towards ICT use. Regarding in-service teachers, recent data examining attitudes are rare and rarely representative.

ICT-related attitudes differ by sociodemographic and professional characteristics (Celik and Yesilyurt 2013). Regarding differences in teaching experience, González-Sanmamed, Sangrà, and Muñoz-Carril (2017) found that teachers with 7 to 20 years of teaching experience report higher positive ICT attitudes. Gender differences in ICT attitudes remain ambiguous. While Pozas and Letzel (2023) found more positive attitudes among male pre-service teachers, González-Sanmamed, Sangrà, and Muñoz-Carril (2017) reported higher average scores for women in an in-service sample. These discrepancies may reflect differing samples and methodological approaches. Attitudes towards ICT seem to be subject specific. Findings by Barak (2014) indicate that Science, Technology, Engineering, and Mathematics (STEM) teachers see ICT as beneficial for teaching due to technological advancements and report greater proficiency among STEM teachers, which mirrors other findings. A study by Dogan, Dawson, and Ritzhaupt (2021) suggests differing attitudes between teachers at different school levels. The authors report more frequent ICT use by elementary school teachers compared to secondary school teachers. The present study takes up these findings to gain more insight into the differences in attitudes towards ICT considering personal and school characteristics.

Self-efficacy, as defined by Bandura (1997), is the belief in one's capabilities to perform certain actions. Scherer and Siddiq (2015) define ICT-related teacher self-efficacy as confidence in performing specific tasks, such as preparing lessons supported by ICT, using specific tools for classroom management, and giving feedback to students digitally. Several studies have shown that it is a crucial predictor of actual ICT integration in the classroom, influencing not only the frequency but also the innovativeness of technology use (Fraillon et al. 2020; Hatlevik and Hatlevik 2018). Recent findings report that teachers show slightly above average self-efficacy in ICT use (Runge et al. 2023).

Gender and age influence ICT-related self-efficacy. Scherer and Siddiq (2015) have found a gender gap for teachers' ICT-related self-efficacy with men exhibiting stronger self-efficacy in operational and collaborative skills, but no difference in instructional ICT use. Regarding age, Fraillon et al. (2020) show higher self-efficacy for teachers younger than 40 years. Research indicates that Science, Technology, Engineering and Mathematics (STEM) teachers often exhibit greater self-efficacy in using ICT compared to their non-STEM counterparts suggesting that STEM teachers perceive ICT as beneficial for innovative education due to technological advancements and the availability of innovative learning environments (Barak 2014). In previous studies, elementary school teachers displayed higher ICT-related self-efficacy (X.-N. Wu, Liao, and Guan 2024).

Research contributions have provided insights into teachers' ICT-related attitudes and self-efficacy; however, they are accompanied by the lack of representative data on how these factors vary among teachers. Additionally, while some studies explore demographic and subject-specific differences, there remains a lack of comprehensive data that integrates these dimensions with varying school levels and contextual factors. Therefore, there is a need for representative data to address these gaps, offering a nuanced understanding of the interplay between personal, professional, and contextual factors in influencing attitudes and self-efficacy (Šabić, Baranović, and Rogošić 2021).

While attitudes and self-efficacy are recognised as critical predictors for teachers' ICT use, there is limited representative research on how these factors can be effectively developed and strengthened. General research on attitudes and self-efficacy suggests that knowledge and skills can be explicitly built through structured learning opportunities, such as professional development programs, and it stands to reason that ICT-related attitudes and self-efficacy could similarly benefit from targeted interventions (Kao et al. 2020).

Teacher professional development

Teacher professional development (TPD) is a 'structured, facilitated activity for teachers intended to increase their teaching ability' (Sims and Fletcher-Wood 2021, 7). It fosters attitudes and self-efficacy leading to improved teaching and student outcomes (Jimoyiannis 2010; Mouza, Codding, and Pollock 2022).

TPD can be categorised into formal and informal types. Formal TPD includes structured programs like workshops (Richter et al. 2014) conducted face-to-face and/or online (Mulaimović et al. 2025), following a systematic curriculum (Darling-Hammond, Hyler, and Gardner 2017). Informal TPD involves unstructured learning activities such as peer collaboration, mentoring, self-directed learning, and participation in professional learning communities (Lecat et al. 2020) – either face-to-face and/or online (Kyndt et al. 2016).

TPD programs focused on ICT use are designed to enhance technical skills and pedagogy for technology use (An 2018). Studies show that teachers who participate in extensive ICT-related TPD programs experience higher confidence in their abilities to adopt digital tools (Bui 2022; B. Wu et al. 2016). Additionally, supporting teachers' ICT self-efficacy can also reduce their anxiety towards integrating technology (Efe, Efe, and Yücel 2016). Consequently, inadequate or poorly designed technology training can prevent teachers from effectively integrating ICT into their classrooms.

Structured learning experiences enhance teachers' confidence and competence in using ICT, leading to more positive attitudes towards technology integration (Fütterer et al. 2023). However, the rapid technological changes require continuous updates of content and teaching methods. Learning through isolated and mandatory in-service training cannot necessarily provide enough learning opportunities for teachers to stay on track with current developments. Informal TPD opportunities, through collaboration with colleagues or self-directed learning, can be an essential part of modern TPD significantly supporting teachers' intentions and abilities to integrate technology (Kyndt et al. 2016). Informal learning through reflection, student and colleague interaction, are significantly associated with positively impacting teachers' ICT attitudes and self-efficacy (Xianhan et al. 2022). For example, a teacher learns about an educational app from a colleague, experiments with it, and gains confidence in ICT integration, leading to increased use.

While research suggests a limited relationship between formal TPD and changing teacher beliefs and behaviour, informal TPD significantly shapes ICT attitudes and self-efficacy (Hoekstra et al. 2009; Verberg, Tigelaar, and Verloop 2013). Differences between formal and informal TPD are well-researched in very specific areas, such as university-based PD programs (Abdul Razzak 2013) or mentoring (Stan 2021) but there is a lack of representative analysis of the relationship between formal/informal TPD and teachers' ICT-related attitudes and self-efficacy.

The present study measures the number of formal and informal professional development activities as a proxy for professional development intensity. These variables were included as predictors in the regression models to estimate their influence on teachers' ICT-related attitudes and self-efficacy.

Research aims

This study aims to contribute to a deeper understanding of the level and preconditions of teachers' attitudes and self-efficacy towards digital tools, which are highly relevant for their effective use in and outside the class. More precisely, we first aim to describe how German teachers think about the utility of digital tools in fostering students' learning. Similarly, we will describe the level of self-efficacy in using digital tools. In addition, we analyse whether sociodemographic characteristics such as job experience, gender, school type, and subject taught are significantly related to attitudes and self-efficacy. Second, we examine whether teachers' participation in formal and informal teacher learning activities can predict their attitudes towards and self-efficacy in ICT use.

Research question 1

What levels of attitudes towards and self-efficacy in ICT use are present among teachers in the German school system, and how do these correlate with each other?

Research question 2

How do formal and informal teacher learning activities, alongside personal and school-related characteristics, predict teachers' attitudes towards and self-efficacy in ICT use?

Methodology and methods

Sample and procedure

This study utilises data representative for the German teacher population from the Deutsches Schulbarometer (German School Barometer) which is conducted by the German public opinion and social research institute Forsa on behalf of the Robert Bosch Foundation. The survey covers general and vocational schools across Germany,[1] including a range of topics such as digital-supported teaching, job satisfaction and stress, school collaboration, professional development, and feedback.

A total of 1608 teachers participated via online questionnaire between October 18 and 3 December 2023. Teachers were recruited by a company specialised in survey research and they made use of a panel of educators, which is regularly used for representative surveys in Germany. While the panel does not perfectly mirror the national teacher population, statistical weights were applied to align the realised sample with official population distributions for region (federal states), school type, and gender, thereby improving representativeness. The findings can be generalised to all teachers in Germany with a possible error margin of ±3% points.

The demographic composition of the sample included 59.8% female participants with 20.1 years (SD = 10.0) of average teaching experience. 79.6% of the sample have a degree in education and 82.7% completed traditional teacher training. 20.3% of the teachers in the sample are either principals or deputy principals in their schools. 18.5% of the teachers in the sample teach at elementary school level. 44.2% are STEM teachers in the sample.

Measures

The study focuses on two dependent variables: attitudes towards the use of digital media and self-efficacy in ICT use. Attitudes towards ICT use are measured using four items based on Carstensen et al. (2022) assessed on a four-point Likert scale ranging from 1 (completely disagree) to 4 (completely agree) with a reliability rating of $\alpha = .80$ (see Table 1). Self-efficacy in ICT use is measured with five items (Carstensen et al. 2022), again assessed on a four-point Likert scale ranging from 1 (completely disagree) to 4 (completely agree) with a reliability rating of $\alpha = .85$ (see Table 1).

The first independent variable 'Participation in ICT-related learning activities' differentiates between no participation (0) and participation in ICT-related learning activities (1). This binary variable describes whether teachers have participated in at least one

Table 1. Descriptive statistics of dependent and independent variables.

Variable	Sample item	*N*	*M*/%	*SD*	*α*
Dependent Variables					
(1) Attitudes towards ICT use	The use of digital media has the potential to reduce the many demands placed on teachers in the classroom.[1]	1592	2.73	.62	.80
(2) Self-efficacy in ICT use	I feel competent in using digital media in the classroom.[2]	1599	2.73	.66	.85
Independent Variables					
(3) Participation in ICT-related learning activities	Have you participated in at least one learning activity related to digital media in the past 12 months?[3]	1444	*66.7%*	–	–
(4) Number of different formal learning activities	In which of the following learning activities have you participated in the past 12 months?	1608	1.03	.68	–
(5) Number of different informal learning activities	In which of the following learning activities have you participated in the past 12 months?	1608	1.00	.79	–

Notes.
[a]4-point Likert scale containing four items; 1 (completely disagree) to 4 (completely agree).
[b]4-point Likert scale containing five items; 1 (completely disagree) to 4 (completely agree).
[c]Dichotomous: no participation (0) and participation (1).

Table 2. Overview of TPD activities.

TPD category	TPD activity
Formal TPD	• TPD programs • Educational conferences • Formal qualification programs
Informal TPD	• Peer observation at other schools • Participation in a network of teachers specifically formed for professional development • Reading professional literature

professional development activity related to digital media or not in the 12 months prior to the survey.

The second independent variable 'Number of different formal learning activities' represents the number of different forms of formal TPD activities in which teachers participated over the last 12 months. Participants could make a multiple selection from three different TPD activities (see Table 2) which were self-developed based on a previous TALIS study (OECD 2018). If teachers did not participate in any of the three formal TPD activities, the variable is coded as 0. Conversely, teachers who participated in all three activities at least once receive a score of 3.

The third independent variable 'Number of different informal learning activities' captures the variety of informal TPD activities in which teachers engaged. Similar to the formal TPD variable, this measure reflects the number of distinct informal activities teachers participated in over the last 12 months. If a teacher did not engage in any informal TPD activity, the variable is coded as 0, whereas engagement in all listed activities at least once results in a score reflecting the maximum level of participation.

In the German teacher education system, continuing professional development (CPD) is largely decentralised and organised at the state level. State-approved providers offer a wide range of opportunities, from short workshops to year-long programs, covering both content-specific and pedagogical themes. Within this context, formal learning opportunities typically include structured formats such as workshops, in-service training days, or online courses offered by state institutes. Informal learning opportunities, in contrast, encompass self-directed activities such as experimenting with digital tools, exchanging practices with colleagues, or following educational media. Our study does

not focus on a single intervention but considers teachers' general engagement in these diverse forms of learning, reflecting the heterogeneity of CPD in Germany. This approach to capturing teachers' CPD engagement is consistent with international research on teacher professional development (e.g. Kirsten et al. 2023).

Covariates in the analysis include the teachers' gender (dichotomous, 0 = male, 1 = female/other). The study also includes the job experience which is measured in years. Additionally, school types (dichotomous, 0 = secondary school, 1 = primary school) and STEM (dichotomous, 0 = not a STEM teacher, 1 = STEM teacher) teaching activities are taken into consideration due to results from existing research.

Data analysis

The first research question is answered using descriptive statistics. To answer the second research question, statistical analysis is performed using multiple regression to examine the relationships between independent and dependent variables. Separate regression models are conducted for ICT-related attitudes and self-efficacy. The analysis proceeds in three main steps: first, the effect of teaching experience, gender, school type, and STEM teaching activity on each of the dependent variables is examined (Models 1 and 2). The second step includes participation in ICT-related professional development programs (Models 3 and 4). In a third step, the sums of different forms of formal and informal learning opportunities are included to observe changes in predictive power (Models 5 and 6). All analyses are conducted using SPSS version 29.0.1.1. Model fit is assessed and considered to be adequate.

Missing data were found to be completely at random, as confirmed by Little's MCAR test (Little 1988). For dependent variables, missingness ranged from 0.5% to 1.0%, and from 0.25% to 10.0% for independent variables. To ensure robust estimation and retain statistical power, 15 imputations were performed using SPSS version 29.0.1.1. Z-standardisation was applied to place all predictors on a common scale, allowing for direct comparison of regression coefficients and improving interpretability of effect sizes after imputation.

Results

Research question 1

Descriptive statistics which are used to answer the first research question offer the following insights. The dependent variables measured are attitudes towards the use of digital media and self-efficacy in ICT use. The mean scores for both attitudes towards ICT use ($M = 2.73$, SD = 0.62) and self-efficacy in using ICT ($M = 2.73$, SD = 0.66) indicate that teachers hold slightly above-average positive attitudes and self-efficacy concerning ICT use. This suggests a generally favourable outlook and confidence level towards digital media among the sample.

Analysis of the correlation between attitudes towards and self-efficacy in ICT use shows a significant positive correlation between the two dependent variables ($r = .45$, $p < .01$). The significant positive correlation between attitudes and self-efficacy highlights that

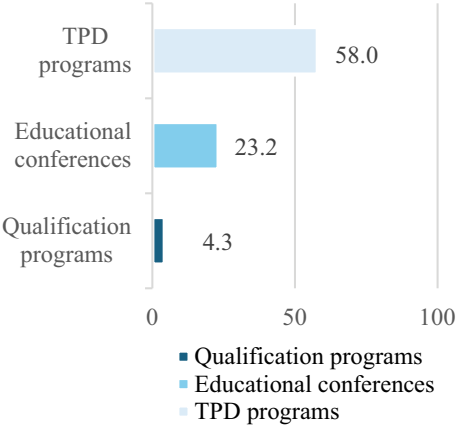

Figure 1. Percentage of participation in different formal TPD activities.

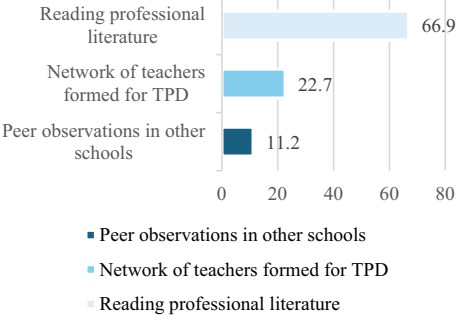

Figure 2. Percentage of participation in different informal TPDactivities.

teachers who view ICT more favourably also tend to feel more confident in their ICT skills and vice versa.

Independent variables include participation in ICT-related learning activities and participation in differing formal and informal learning activities within the last 12 months. Regarding ICT-related learning activities related to digital media, results show that 66.7% of participants engage in such activities. Participation in different forms of formal and informal TPD is shown in Figures 1 and 2 below. Regarding formal TPD, 58.0% of the teachers in our sample participate in formal TPD programs, 23.2% in educational conferences and 4.3% in formal qualification programs. Regarding informal TPD, 66.9% of teachers read professional literature, 22.7% of the teachers participate in networks specially formed for TPD and 11.2% take part in peer observations in other schools.

The correlations between dependent and independent variables (see Table 3) show a significant negative correlation between job experience and attitudes towards the use of digital media ($r = -.11$, $p < .01$) and self-efficacy in using digital media ($r = -.10$, $p < .01$). Additionally, self-efficacy in using digital media significantly and negatively correlates with gender ($r = -.05$, $p < .05$), positively correlates with STEM teaching activity ($r = .13$, $p < .01$), participation in learning activities related to digital media ($r = .14$, $p < .01$), differing formal learning activities ($r = .16$, $p < .01$) and differing informal learning activities ($r = .17$,

Table 3. Correlations between dependent variables and independent variables.

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Job Experience	1								
(2) Gender[1]	.04	1							
(3) School type: Primary school[2]	.04	.24**	1						
(4) STEM teaching activity[3]	.02	−.01	.13**	1					
(5) Attitudes towards ICT use	−.11**	−.04	−.03	.03	1				
(6) Self-efficacy in ICT use	−.10**	−.05*	−.03	.13**	.45**	1			
(7) Participation in ICT-related learning activities	.05	−.04	−.03	.08**	.05*	.14**	1		
(8) Number of different formal learning activities	.01	.05*	.05	−.004	.06*	.16**	.20**	1	
(9) Number of different informal learning activities	.06*	.02	.02	−.02	.04	.17**	.06*	.35**	1

Notes. *$p < .05$, **$p < .001$.
[1]Dichotomous: male (0) and female/other (1).
[2]Dichotomous: secondary school (0) and primary school (1).
[3]Dichotomous: teachers not teaching STEM teacher (0) and teachers teaching STEM (1).

Table 4. Linear regression models for predicting attitudes and self-efficacy towards the use of digital media in the classroom.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	β (SE)		β (SE)		β (SE)	
Predictor	Attitudes	Self-efficacy	Attitudes	Self-efficacy	Attitudes	Self-efficacy
Job Experience	−.11 (.03)**	−.10 (.03)**	−.11 (.03)**	−.10 (.03)**	−.11 (.03)**	−.11 (.02)**
Gender[1]	−.03 (.03)	−.04 (.03)	−.03 (.03)	−.04 (.03)	−.03 (.03)	−.04 (.03)
School type: Primary school[2]	−.02 (.03)	−.03 (.03)	−.02 (.03)	−.03 (.03)	−.02 (.03)	−.03 (.03)
STEM teaching activity[3]	.04 (.03)	.13 (.03)**	.03 (.03)	.12 (.03)**	.04 (.03)	.13 (.02)**
Participation in ICT-related learning activities	–	–	.06 (.03)*	.13 (.03)**	.04 (.03)	.11 (.03)**
Number of different formal learning activities	–	–	–	–	.05 (.03)	.08 (.03)*
Number of different informal learning activities	–	–	–	–	.03 (.03)	.15 (.03)**
R^2	.01	.03	.02	.04	.02	.08

Notes. *$p < .05$, **$p < .001$.
[1]Dichotomous: male (0) and female/other (1).
[2]Dichotomous: secondary school (0) and primary school (1).
[3]Dichotomous: teachers not teaching STEM teacher (0) and teachers teaching STEM (1).

$p < .01$). These findings imply that STEM teachers and those engaged in diverse informal learning contexts may feel particularly empowered in their ICT competencies.

Research question 2

The first and second linear regression models (see Table 4) indicate that job experience is statistically significantly associated with both attitudes towards use of digital media ($\bar{\beta} = -0.11$, $p < .001$) and self-efficacy in using digital media ($\bar{\beta} = -0.10$, $p < .001$). That means that with increasing experience teachers have less positive attitudes towards and a lower self-efficacy in ICT use. Teaching a STEM subject shows a small, highly significant effect on self-efficacy in ($\bar{\beta} = 0.13$, $p < .001$) but no effect on attitudes towards ICT use. Whereas

gender and school type have no significant effect on either attitudes towards or self-efficacy in ICT use.

The third and fourth model (see Table 4) show a small but significant effect of ICT-related learning activities on attitudes towards ICT use ($\bar{\beta} = 0.06$, $p < .05$) and a stronger, highly significant effect on self-efficacy in ICT use ($\bar{\beta} = 0.13$, $p < .001$). This suggests that engaging in ICT-related learning activities contributes to fostering a more favourable perception of ICT use and enhances teachers' confidence in their ability to effectively use ICT in their professional practice.

Finally, models 5 and 6 (see Table 4) incorporate two further independent variables: The sum of differing formal learning activities has a small but significant effect on self-efficacy in ($\bar{\beta} = 0.08$, $p < .005$) but not on attitudes towards ICT use. The sum of differing informal learning activities shows a stronger, highly significant effect on self-efficacy in ($\bar{\beta} = 0.15$, $p < .001$) but not on attitudes towards ICT use. It is noteworthy that participation in ICT-related learning activities shows no significant effect on attitudes towards ICT use in the fifth model. This suggests that engaging in ICT-related learning activities, as well as participating in a diverse set of formal and informal professional development activities, relates to teachers' confidence in their ability to effectively integrate ICT into their classroom practice. However, these experiences do not seem to relate to their overall attitudes towards ICT use.

Overall, the models demonstrate that participation in a variety of informal learning activities and teaching a STEM subject are the strongest predictors of ICT self-efficacy in ICT use, explaining up to 7.9% of its variance. However, the models account for only a small portion of variance in attitudes towards ICT use (1.2% to 1.7%).

Discussion

The relationship between teachers' attitudes towards and their self-efficacy in the use of ICT in their teaching practices, and the relationship with TPD are investigated in this study. The findings provide valuable insights into the relationship between TPD and effective ICT use in educational contexts.

The present study complements previous research. First, we draw on a representative data set of German teachers. We thus avoid a possible bias due to differential participation in surveys on digitalisation. With a non-representative random sample, it is possible, for example, that people with a positive or negative attitude are more likely to be recruited as participants. The current study allows a representative overview, whereby the values obtained here could serve as a comparison group for future studies. Secondly, the current study is one of the first to examine differences between formal and informal learning opportunities in their relationship to teacher's ICT-related attitudes and self-efficacy.

Our analysis of mean scores reveals that teachers in Germany generally view ICT as moderately effective, indicating a more neutral stance towards its potential impact on classroom management and instruction. This suggests that while teachers may not view ICT as particularly transformative, they are not dismissive of its utility either. In accordance with research which shows a decline in teachers' ICT use in the last three years (Pozo, Cabellos, and Del Puy Pérez Echeverría 2024), our results indicate that teachers still perceive ICT's influence on their classrooms as moderate rather than

overwhelmingly positive. The regression analysis identified a significant negative relationship between job experience and attitudes towards ICT, suggesting that less experienced, typically younger teachers, may be more familiar with technology. This familiarity could account for their more positive views on ICT, potentially influenced by their exposure to ICT during their own education. This digital age divide is captured in frameworks like Prensky's 'digital natives' vs. 'digital immigrants' (Prensky 2009), which suggest that younger teachers might intuitively adapt to ICT, while more experienced teachers could face steeper learning curves. However, Prensky's framework has been challenged in the classroom with most recent research indicating that in-service teachers show even better developed ICT competences than pre-service teachers (Rubach et al. 2023).

The strong correlation between attitudes and self-efficacy suggests a relationship: individuals with positive attitudes towards ICT are also likely to report higher self-efficacy in its use, though the direction of causation cannot be determined from this correlation. Successful ICT experiences may foster more favourable attitudes, creating a reinforcing feedback loop (Rangel-Pérez et al. 2021). According to Bandura's Social Cognitive Theory (Bandura 1997), self-efficacy is a central factor in shaping motivation and behaviour, with positive attitudes enhancing confidence in one's abilities. Conversely, strong self-efficacy beliefs can lead to more positive attitudes towards specific tasks or behaviours (Kırkız and Çetinkaya 2020).

Teacher professional development (TPD) presents a potential for enhancement within the context of attitudes towards and self-efficacy in ICT use. However, our findings indicate that neither formal nor informal TPD activities show a significant effect on teachers' attitudes towards ICT use in the classroom. This aligns with intervention studies suggesting that participation alone in TPD may not be sufficient to shift teachers' perceptions of ICT (Sánchez et al. 2012). The limited relationship between TPD activities and teachers' attitudes towards ICT aligns with theoretical models of change and adoption in educational contexts (Granić 2022). TPD programs implemented on a broad scale may not be effective, potentially due to insufficient quality; however, the quality of these programs was not considered in our analysis (Kirsten et al. 2023). According to Fullan's (1992) Change Theory, effective integration of innovations, such as ICT, requires more than just exposure through training; it involves a series of stages that move from awareness to implementation, ultimately leading to deeper internalisation and attitude change. This theory suggests that, in the context of ICT, teachers might only experience significant shifts in attitude after sustained and practical engagement with technology in their classrooms. Training alone may spark initial awareness, but hands-on application and reflective practice are essential for fostering the personal investment needed to fully embrace ICT as a beneficial tool in teaching. Thus, while TPD can lay the groundwork for ICT use, continuous, practical support and opportunities to implement ICT in real teaching scenarios are necessary for more profound changes in attitudes. It becomes clear that professional development should go beyond one-off sessions. Instead, TPD might benefit from a more iterative approach that includes direct application and reflection to better support teachers in progressing through these stages of adoption. This approach could help teachers bridge the gap from merely understanding ICT's potential to actively

valuing and using it in their classrooms. Results of this study reinforce this demand by showing that participation in ICT-related TPD has a small but significant effect on attitudes towards ICT use which suggests the importance of continuous training in ICT use.

A distinct pattern emerges with respect to self-efficacy, where the observed learning activities – including ICT-related learning activities, formal, and informal professional development – show significant effects on self-efficacy in ICT use. This means that participation in ICT-related TPD activities predicts ICT self-efficacy which mirrors former research (e.g. Drossel and Eickelmann 2017). Studies have shown a positive relationship of self-efficacy and TPD participation which might translate to teachers with higher ICT self-efficacy being more likely to participate in ICT-related TPD (Liu and Liao 2019). When comparing the relationship of formal and informal learning activities and self-efficacy in ICT use it becomes clear that teachers' informal learning has a greater effect on self-efficacy in ICT use. Formal TPD is frequently conducted as one-time, pre-structured events, often with limited follow-up or integration into teachers' practices (Kirsten et al. 2023). By contrast, informal learning activities provide teachers with greater autonomy and the opportunity for peer collaboration, which may foster more meaningful, sustained engagement with ICT. Teachers do not receive any support in implementing knowledge or skills, which they have learned at a TPD session, into their everyday teaching routines. The very common one-size-fits-all approach of formal TPD also provides less opportunity to fulfill the needs and interests of each individual teacher. Informal types of learning seem to be more fitting in that respect. Additionally, motivation to participate in formal and informal TPD might differ, leading to differentiating effects on attitudes towards and self-efficacy in ICT use. Following the self-determination theory (Ryan and Deci 2017), teachers' experience of autonomy can be a pre-requisite for effective TPD. Firstly, the need for autonomy is fulfilled if a person can voluntarily choose which field they want to improve in comparison to being forced to participate in an in-house TPD. Secondly, the aspect of relatedness is taken up in informal learning because most include some kind of peer collaboration, such as professional learning networks (PLNs) in which teachers support each other when faced with the challenge of implementing new technology, for example (Lewin et al. 2009). This support, whether it is instrumental, informational or emotional, does not necessarily have to happen synchronously on-site but can also be conducted asynchronously in online spaces (E. Richter et al. 2022). Thirdly, the need for competence is covered when teachers are neither overwhelmed nor unchallenged by TPD activities. When learning in informal settings, teachers choose the input in accordance with their current level of expertise. Also, the immediacy of informal learning allows teachers to instantly implement new learnings into practice allowing for immediate feedback. Thus, self-directed learning, supported by choice, peer collaboration, and constructive feedback, appears to address teachers' individual needs more effectively than standardised TPD, fostering greater self-efficacy in ICT use (Power and Goodnough 2019). Chiu et al. (2024) can show that 'the satisfaction of the needs for autonomy, competence, and relatedness' (p. 11) in their professional development is an indirect predictor of teachers' ICT self-efficacy. Informal learning activities seem to better incorporate the features of self-determination than formal learning activities.

Limitations

This study has several limitations that should be acknowledged. First, the cross-sectional design restricts the capacity to draw causal inferences between ICT-related attitudes, self-efficacy, and teachers' professional development activities, allowing only correlational interpretations of these relationships. A longitudinal design would be necessary to observe changes over time, particularly regarding how attitudes and self-efficacy evolve with TPD engagement and hands-on ICT experience.

Additionally, the study's measure of TPD captures only the variance in types of learning activities undergone rather than a cumulative measure or detailed assessment of professional growth. This proxy approach limits our understanding of the quality, duration, and integration of professional development activities, factors that may play a critical role in influencing attitudes and self-efficacy. As noted in the discussion, the structure and voluntariness of professional development – particularly informal versus formal settings – could meaningfully impact ICT self-efficacy. Future research should consider more comprehensive assessments of TPD that account for the frequency, duration, and teachers' usage experience (Fütterer, Richter, and Richter 2024).

Conclusion & implications

Despite limitations, this study confirms that informal learning activities have a stronger predictive effect ($\beta = 0.15$) on ICT-related self-efficacy than formal TPD ($\beta = 0.08$), underscoring their value for professional learning. The use of both quantitative measures and a representative sample of teachers provides robust insights into how TPD activities predict ICT-related attitudes and self-efficacy. These strengths underscore the broader applicability of our findings to TPD research and practice.

Further research should explore how different learning opportunities can be interwoven to maximise impact on teachers' ICT attitudes and self-efficacy. Value-added studies could provide insights into how formal and informal learning experiences interact to support teachers' ICT-related development. For instance, it could be investigated how formal training might best be supplemented by informal learning, such as professional learning networks (PLNs). Understanding these interactions is essential for designing TPD programs that sustain positive changes.

Another direction of research should investigate the processes by which teachers internalise and apply TPD content over time. Longitudinal studies could track ICT-related attitudes and self-efficacy through sustained TPD, offering deeper insights into the development of these factors and giving a fuller picture of how TPD influences teaching practices. Formal TPD must ensure lasting impact beyond brief sessions by providing sustained engagement, support for implementation, and follow-up reflection. This structured approach can help teachers internalise what they learn and foster positive ICT-related attitudes and self-efficacy.

These findings underscore the importance of aligning TPD design with teachers' actual learning preferences and workplace realities. Previous research has shown that practical implementation such as a blended approach combining structured formal sessions with flexible, peer-driven formats can be very effective (Earle 2024). For instance, schools might integrate regular digital mentoring into existing schedules, encourage participation in

professional learning networks (PLNs), or create collaborative planning time for integrating ICT into lessons. In addition to Earle's (2024) suggestions, our findings indicate that TPD initiatives may be most effective when they combine structured formal inputs with sustained informal learning opportunities. For example, a program might begin with a focused workshop on digital pedagogy, followed by collaborative lesson design sessions and peer coaching phases that allow teachers to test and adapt innovations within their everyday practice. Such blended models could foster both competence and confidence in ICT use.

Furthermore, TPD programs should address teachers with negative ICT attitudes and low self-efficacy. These teachers are less likely to engage in self-directed learning and may feel disconnected from digital innovations in education. Targeted interventions, including motivational strategies, one-on-one-coaching, and supportive school leadership, can boost this group's engagement and confidence in ICT use. Peer-based strategies could involve rotating digital tandems, where a more confident teacher pairs with a colleague for a specific lesson cycle, or ICT learning cafés, brief informal sessions during which staff exchange concrete classroom practices. Shadowing sessions, i.e. observing a peer using digital media, can further strengthen perceived self-efficacy (Abedi and Korkor Ametepey 2024).

TPD must be flexible and differentiated to meet diverse teacher needs, offering multiple pathways for engagement, including a balance of formal and informal learning opportunities. Options for peer collaboration, self-paced learning, and reflective practice can better support teachers at various stages of ICT adoption. Recognising and addressing the diversity in teachers' starting points with ICT may enhance the effectiveness of TPD initiatives and contribute to more consistent and impactful ICT integration in classrooms.

Note

1. In the German educational system, young adults are able to leave general school after 9th or 10th grade starting a structured 3-year job training which involves training with a company, as well as vocational school.

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