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Comparison of pre- and in-service primary teachers' dispositions towards the use of ICT

Lars Jenßen[1] · **Katja Eilerts**[2] · **Frederik Grave-Gierlinger**[2]

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Abstract

There is widespread agreement, that today's students must develop competencies in the efficient use of information and communication technology (ICT) to cope with the demands of the 21st century. To meet this requirement, teachers must integrate ICT into their classroom activities on a regular basis. Studies have shown that the use of ICT in the classroom correlates with the level of professional knowledge and with affective-motivational dispositions (such as emotions and self-efficacy) of teachers. However, the relations between these dispositions and the extent to which these relations differ between pre- and in-service teachers have not yet been investigated. Hence, the present study examines the dispositions of 148 German pre-service and 132 German in-service primary school teachers to use ICT in geometry classes and tests for differences between these groups. To this end, a series of path models have been investigated on the basis of control-value theory in a quantitative study. Results of the invariance testing revealed only minor differences in the relations between the investigated dispositions: For in-service teachers a negative correlation between the assumed value of ICT for teaching geometry and the professional knowledge regarding ICT was found. The same does not hold true for pre-service teachers. Apart from this difference, however, the two groups were very similar. It can therefore be concluded that learning opportunities regarding the use of ICT in geometry classes do not need to differ greatly for the pre-service and in-service teachers.

Keywords Control-value theory · Enjoyment · Teaching self-efficacy · Teachers · Digital tools · Mathematics

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Extended author information available on the last page of the article

1 Introduction

Information and communication technologies (ICT) are effective means to support learning processes; both in general and for learning geometry at a primary level in particular (Arvanitaki & Zaranis, 2020; Choi-Koh, 1999; Zaranis & Synodi, 2017). However, the actual effectiveness of ICT depends largely on a teacher's competence to integrate ICT into their classroom activities (Hillmayr et al., 2020). Hence, there is a demand for teachers, able to effectively use ICT as a tool for learning mathematics (Daher et al., 2018; Monaghan et al., 2016). In this context it is noteworthy that teachers generally perceive ICT as valuable and yet many do not feel prepared to use ICT in the classroom (Fraillon et al., 2019). A reason might be that there is a broad variety of tools available for teaching and learning mathematics: Teachers have computer algebra systems, spreadsheet programs, dynamic geometry environments, intelligent tutoring systems, interactive worksheets, programmable robots, microcontrollers, and a vast amount of math applications and apps at their disposal. Knowing what tools exist for a specific learning goal and when these tools have the potential to enrich classroom activities is far from trivial and poses a complex challenge for teachers. This is especially true in Germany, where teachers exhibit comparatively low levels of competence and confidence in the use of ICT as a didactic tool (Fraillon et al., 2019). Making matters worse, the *Trends in International Mathematics and Science Study 2019* indicates that primary school teachers in Germany take part in fewer training courses on the use of ICT for teaching mathematics than their European and international colleagues (Guill & Wendt, 2020). Consequently, there is an urgent need for research on the design of courses that allows teacher educators to prepare pre- and- in-service teachers as effectively and efficiently as possible to use ICT in mathematics. (Monaghan et al., 2016). It is noteworthy that pre- and in-service teachers can both be construed as learners in this context (Prediger et al., 2019), even though in-service teachers have more professional experience and a more developed identity as a teacher. Given their different backgrounds one would generally assume that formal learning opportunities (such as teacher education programs for pre-service teachers and professional training programs for in-service teachers) must offer different content to pre- and in-service teachers. However, in light of the slow pace of digitization in German schools and the low number of learning opportunities in this regard both groups might very well require identical learning opportunities to improve their competence to integrate ICT into their teaching activities. There is a lack of evidence, that might help decide, which of these two assumptions is correct. As a result, it is unclear if and in what ways formal learning opportunities for pre- and in-service teachers should differ, when it comes to learning how ICT can be used as a didactic tool. Existing training programs focus on the knowledge necessary to use ICT in mathematics lessons (Monaghan et al., 2016) and assume, for instance, that learning to use dynamic geometry software helps gain knowledge on how ICT can be integrated meaningfully in geometry lessons (Dockendorff & Solar, 2018). However, professional competence comprises not only knowledge, but also affective-motivational dispositions such as beliefs, emotions, and self-efficacy (Blömeke et al., 2015). In particular, evidence confirms that affective-motivational constructs are relevant variables for predicting the learning outcomes of students in geometry when dynamic geometry software is used as an instructional tool (Greefrath et al., 2018).

2 Teachers' dispositions regarding the use of ICT

Studies have shown that digital tools have the potential to improve the teaching and learning of mathematics (Wenglinsky, 1998; Mistretta, 2005) and there is widespread agreement that modern mathematics education should incorporate ICT: The *U.S. National Council of Teachers of Mathematics* (2015, para. 2) for instance states that "all schools and mathematics programs should provide students and teachers with access to instructional technology". However, to harness the potentials of ICT, mathematics teachers need to know how ICT can be used to improve the quality of their classroom activities and be willing and prepared to act on this knowledge. In accordance with the model of professional competence by Blömeke et al. (2015), we subsume these two aspects under cognitive and affective-motivational dispositions. Teachers' dispositions toward the use of ICT can be understood as a complex of several cognitive and affective-motivational constructs (Seufert et al., 2020); and while emotions are generally considered an important component, most studies focus on unpleasant emotions such as anxiety (Awofala et al., 2019; Saha et al., 2020; Yanuarto et al., 2019) and disregard pleasant emotions like enjoyment. This is reflected in various models which aim to predict a person's use of ICT: While affective-motivational dispositions are usually considered as relevant factors (Venkatesh et al., 2003), emotions tend to get neglected. The *Technology Acceptance Model* (Davis, 1989) for instance specifies relations between affective-motivational characteristics and the intention to use ICT (as well as the actual use of ICT). The model can be considered established (Marangunić & Granić, 2015) and has been validated for various groups; pre-service teachers in mathematics being just one example (Marbán & Mulenga, 2019). The model does not, however, include emotions or professional knowledge as factors. This is regrettable as the study by Scherer et al. (2018) revealed that both affective-motivational variables and knowledge predict the actual use of ICT among pre-service teachers.

2.1 Technological pedagogical content knowledge

The TPACK model (Koehler et al., 2013) assumes three distinct areas of knowledge: technological knowledge, pedagogical knowledge and content knowledge. All of these are deemed important aspects of the professional knowledge of teachers when considering the use of ICT in the classroom: Teachers must have a thorough understanding of the content they intend to teach, they need to know how this content can be taught effectively, and they must be aware of ways in which technology can support the learning experience of their students. The intersection of all three areas represents the technological pedagogical content knowledge (TPCK) of teachers. This general model has already been applied to pre-service mathematics teachers in regards what they should learn during teacher education (Aldemir Engin et al., 2022).

Studies revealed that mathematics teachers' TPCK predicts engagement in digital learning environments (Mailizar et al., 2021). Furthermore, evidence suggests that affective-motivational dispositions are positively related to TPCK (Scherer et al., 2018). It is important to note, however, that the pace at which technology is changing, requires an on-going development of teachers' professional knowledge and complicates the development of objective assessments. It comes as no surprise then, that the multitude of established measures to assess TPCK are based on self-reports in the form of standardized questionnaires (Siddiq et al., 2016; Zelkowski et al., 2013).

2.2 ICT teaching self-efficacy

Self-efficacy is an established construct and describes the subjective belief in one's own competence (Bandura, 1977). With respect to ICT, two conceptions of self-efficacy can be found in the literature: The first (general ICT self-efficacy) describes a person's confidence in using ICT for everyday purposes; the second (ICT teaching self-efficacy) focuses on a person's belief in their ability to use ICT as a didactic tool in the classroom (Jenßen et al., 2021). In both cases, self-efficacy is considered a constituent part of teacher readiness to use ICT (Petko et al., 2018). However, international comparative studies show that many teachers, particularly in Germany, do not consider themselves ready to use ICT in a way that promotes learning activities (Fraillon et al., 2019).

Evidence suggests that ICT teaching self-efficacy can be strengthened through technology-centred student teaching experiences (Han et al., 2017). This is in accordance with the general assumption that experiences in a specific domain are a source of self-efficacy in that domain (Bandura, 1977). The literature furthermore indicates, that positive emotions can be a source of self-efficacy (Bandura, 1977).

2.3 Enjoyment

Enjoyment is as a pleasant and activating emotion (Feldman Barrett & Russell, 1998) that can be experienced before, during, or after learning situations as well as achievement situations (Pekrun, 2006). It triggers approach behavior and increases interest in learning (Ainley & Hidi, 2014). Additionally, enjoyment can lead to the experience of *flow*, thereby promoting deeper and more persistent engagement with the content to be learned and a higher willingness to invest time in the subject. This effect has been studied and documented in different educational settings for both pre-service (Montoro & Gil, 2019) and in-service teachers (Russo et al., 2020); and it has been validated for the engagement with and the use of ICT in general (Agarwal & Karahanna, 2000). Studies have furthermore demonstrated empirical connections between emotions and technology acceptance (Mac Callum et al., 2014) and specifically between emotions and the decision to use ICT as a tool for teaching mathematics (Kaleli-Yilmaz, 2015).

The extent to which teachers enjoy teaching mathematics correlates with their experiences of enjoyment as learners of mathematics, not only, but also during teacher education or in professional training programs (Russo et al., 2021). Additionally, the enjoyment experienced by a teacher contributes to their students' enjoyment for learning (Frenzel et al., 2018). Hence, teacher education and professional training should aim to promote the experience of enjoyment.

2.4 Appraisals

In the context of control-value theory, appraisals are judgments or beliefs about the perceived control over and value of a situation, domain, or object (Pekrun, 2006). In what follows *control appraisal* denotes a measure for the extent to which teachers perceive that they have control over ICT (Jenßen et al., 2021) and *value appraisal* refers to the importance teachers ascribe to the use of ICT in the classroom (Sadaf & Johnson, 2017).

Control and value appraisals have both been shown to correlate with the affective-motivational experience of teachers (Grave-Gierlinger et al., 2022; Jenßen et al., 2021; Stephan et al., 2019). Studies furthermore indicate that the frequency of technology use in the classroom relates positively to both appraisals (Sadaf et al., 2012). For the most part, teachers ascribe a high value to ICT (Fraillon et al., 2019) but differ significantly in terms of control appraisal; in part (but not only) due to the vastly different availability of technology in schools (Sadaf & Johnson, 2017).

2.5 Relations between dispositions

In contrast to other theoretical models, control-value theory (Pekrun, 2006) integrates and describes relations between affective-motivational dispositions (appraisals, emotions, self-efficacy expectations) and cognitive dispositions (especially knowledge). The theory has been successfully applied to various domains and different learning situations such as teacher education courses developed for pre-service mathematics teachers (Jenßen et al., 2021) and professional training programs on using ICT for teaching geometry (Grave-Gierlinger et al., 2022). The model can thus serve as a theoretical basis to investigate the relations and interactions between cognitive and affective-motivational dispositions and examine how these variables affect teacher's competence and readiness to use ICT in the classroom (Yanuarto et al., 2019).

Studies revealed control appraisal to correlate positively with self-efficacy to use ICT in the classroom (Li et al., 2019), validating a basic assumption of control-value theory for teachers. Empirical evidence furthermore suggests that high control appraisal and high value appraisal are associated with higher levels of enjoyment (Ainley & Hidi, 2014; Tze et al., 2021). This is an important finding, given that the experience of enjoyment is considered an important factor for the development of one's self-efficacy expectation (Bandura, 1997): In particular, studies confirmed that enjoyment regarding the use of ICT positively predicts ICT self-efficacy (Yi & Hwang, 2003) and is a positive predictor of pre-service teachers' ICT teaching self-efficacy in mathematics (Jenßen et al., 2021). Meta-analytically, enjoyment has a positive medium correlation with academic achievement (Camacho-Morles et al., 2021), which can be explained by the fact that enjoyment has positive effects on cognitive capacity (Pekrun, 2006) thereby facilitating learning processes and improving achievement outcomes (Putwain et al., 2020). Similarly, self-efficacy mediates between the experience of enjoyment in a particular domain and knowledge in that domain (Bandura, 1977; Pekrun, 2006).

Some studies adopt assumptions of control-value theory to examine the relation between teachers' cognitive and affective-motivational dispositions. However, there is a lack of empirical research that includes appraisals, emotions, self-efficacy and knowledge. A fortiori, there is also a lack of studies exploring differences and similarities between pre-service and in-service teachers in this regard.

3 Research question and hypotheses

The primary purpose of the present study was to examine the relations between primary mathematics teacher's cognitive dispositions (i. e. technological pedagogical content knowledge) and affective-motivational dispositions (i. e. appraised control over ICT; appraised value of ICT; enjoyment regarding the use of ICT; ICT teaching self-efficacy) to use ICT as an instructional tool in geometry classes. The second objective of the study was to compare pre- and in-service teachers with respect to the found relations between cognitive and affective-motivational dispositions. To clarify: The goal was not to identify separate models for the two groups, but to uncover differences and similarities in a single model. Consequently, the following research question was formulated:

Research question 1 (RQ1): Are there differences in the relations between pre-service and -in-service primary school teachers' dispositions towards the use of ICT in geometry classes? Related to this question, the relations between dispositions for the overall model should be determined.

Given that the level of readiness to use ICT as an instructional tool is comparatively low for pre-service and in-service teachers in Germany (Fraillon et al., 2019; Guill & Wendt, 2020) both groups can be conceived of as learners in the present context. We thus assume as first hypothesis (H1) that relations between the investigated dispositions are the same for pre-service and in-service teachers, both in the sense of existence (significance) and polarity (positive or negative).

Since control-value theory describes a cascade of effects, several variables act as both predictors and outcomes. This led to the second research question (RQ2): How do the independent variables affect the dependent variables of the proposed model?

Specifically, we hypothesize here that (H2a) control and value appraisals are positively related to each other, (H2b) control and value appraisals have direct effects on enjoyment and indirect effects on ICT teaching self-efficacy and technological pedagogical content knowledge, (H2c) enjoyment shows direct effects on self-efficacy and indirect effects on technological pedagogical content knowledge, and lastly (H2d) self-efficacy is related directly and positively to technological pedagogical content knowledge. Whether the size of the effects between the dispositions is the same, is an additional exploratory research question (RQ3).

We included age, gender, and job experience as control variables in our theoretical model as studies suggest these might be relevant when it comes to teachers' professional competence regarding the use of ICT (Choi et al., 2018; From, 2017; Scherer et al., 2015; Scherer & Siddiq, 2015; Siddiq & Scherer, 2016). The proposed model is presented in Fig. 1.

4 Materials and methods

4.1 Sample

All participants of the study were primary school teachers from Germany (grade 1–6). The group of pre-service teachers were recruited from a university seminar designed to teach and encourage the use of ICT in geometry classes ($n=148$). The in-service teachers were surveyed at the beginning of a professional training program which too was designed to teach and encourage the use of ICT in geometry classes ($n=132$).

The majority (82.4%) of pre-service teachers identified as *female* (17.6% male, 0.0% diverse). They were $M=27.98$ years old on average ($SD=8.20$; $Min=20$, $Max=53$) and although pre-service teachers can legally work as substitute teachers in Germany even before finishing their studies, only few pre-service teachers indicated that they have job experience as teachers ($M=0.59$ years, $SD=1.04$; $Min=0$, $Max=6$). From the average number of semesters studied ($M=5.81$, $SD=1.22$; $Min=1$, $Max=10$) it can be gleaned, that most pre-service teachers, who took part in the study, were in the bachelor's program. They indicated on a 5-point scale ranging from 0 (=not at all) to 4 (=many) that they had few opportunities to learn about the use of ICT in mathematics classes up to this point ($M=1.35$, $SD=1.12$).

Similarly to the surveyed pre-service teachers, the majority (87.6%) of in-service teachers identified as female and only a minority (12.4%) identified as male; no one indicated diverse as their gender. As expected, in-service teachers were on average older ($M=48.41$, $SD=9.45$; $Min=25$, $Max=64$) than pre-service teachers and had more job experience as teachers with an average of $M=19.91$ years ($SD=13.55$; $Min=1$, $Max=42$). They indicated on a scale ranging from 0 (=not at all) to 10 (=many) that they rarely use ICT as a tool to teach mathematics ($M=3.80$, $SD=2.74$).

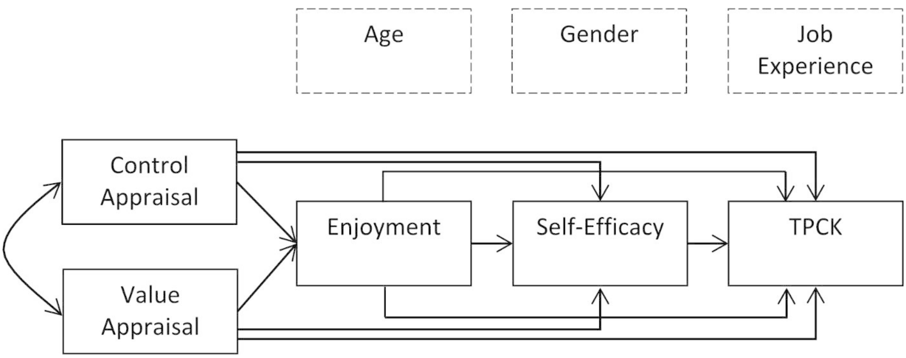


Fig. 1 Theoretical Model

4.2 Assessments and procedure

Pre- and in-service teachers' TPCK was assessed by adapting an existing questionnaire (Schmidt et al., 2009) which has frequently been adopted in past research on teachers' competence to use ICT as instructional tools (Chai et al., 2016). The items were translated into German, slightly re-formulated to make sense for both pre-service and in-service teachers and focused on the use of ICT for teaching geometry. The questionnaire covers five items (e.g., "I can choose technologies that enhance the content for a geometry lesson") to be rated on a scale from 0 (=strongly disagree) to 4 (=strongly agree). The sum score of the scale represents the self-assessed level of primary teachers' TPCK with respect to the use of ICT for teaching geometry.

To assess affective-motivational dispositions, a questionnaire battery which was specifically developed for primary mathematics teachers (Jenßen et al., 2021) was administered. The Items were re-worded slightly by replacing occurrences of the word *mathematics* with *geometry*. All items of the questionnaire must be rated from 0 (=does not apply at all) to 5 (=fully applies). The battery consists of three items for control appraisal (e.g., "It is easy for me to adapt ICT tools to my needs"), four items for value appraisal (e.g., "The use of ICT tools improves the achievement of students in geometry"), three items for enjoyment (e.g., "I enjoy thinking about possible uses of ICT tools for teaching geometry"), and four items for ICT teaching self-efficacy (e.g., "I believe I can use ICT tools in a way that facilitates learning processes in geometry"). All items used in the current study are given in Appendix A.

Pre-service teachers filled out the complete questionnaire at the beginning of the university seminar. In-service teachers completed questionnaire at the beginning of the professional training program. No incentives were given for participation in the study and all participants were free to withdraw from participation at any point without consequences.

4.3 Data analysis

To allow for the investigation of relations between variables that are both dependent and independent within a single model, path analysis was used (Stage et al., 2004; Cohen et al., 2003). The model was specified in accordance with the theoretical model presented in Fig. 1. The first research question (i. e. "Are there differences in the relations between pre-service and in-service primary school teachers' dispositions towards the use of ICT in geometry classes?") was investigated by invariance testing for both groups. An unrestricted model (in which all coefficients were freely estimated for pre-service and in-service teachers), a restricted model (in which all coefficients for pre- and in-service teachers were set equal) and a partially restricted model were analyzed.

Wald tests were performed to identify significant differences between the regressive coefficients of the two groups and develop the partially restricted model: In case of significant differences, the coefficients of the partially restricted model were freely estimated, while all other coefficients were set equal. Model comparisons were performed by applying chi-square-difference tests. Common fit indices were used to evaluate model fit (Hu & Bentler, 1999). All hypothesized direct, indirect, and total effects were estimated for the final path model.

5 Results

5.1 Descriptive results

Mean values and standard deviations for all variables are presented in Table 1. The numbers are listed separately for pre- and in-service teachers. It has to be noted that the TPCK variable could range from 0 to 20, Control Appraisal and Enjoyment from 0 to 15, and Value Appraisal and also Self-Efficacy from 0 to 20. According to the *p*-values, there were significant differences between the two groups regarding age ($t(251.64)=19.01$, $p<.01$) and work experience ($t(128.97)=16.07$, $p<.01$), but not regarding gender ($\chi^2(1)=1.43$, $p=.23$)[1].

Table 2 gives an overview of the reliabilities measured with Cronbach's Alpha for all variables. Reliabilities ranged from acceptable (0.61 and 0.63 respectively for Control Appraisal) to very good (0.90 for Self-Efficacy).

Table 1 Descriptive results

	Pre-service teachers		In-service teachers	
	M	*SD*	*M*	*SD*
Control Appraisal	10.18	2.34	9.83	2.41
Value Appraisal	13.64	2.89	14.24	2.74
Enjoyment	9.90	2.84	9.98	2.98
Self-Efficacy	13.55	3.62	12.88	3.81
TPCK	8.82	4.39	8.53	4.09

Note. M=Mean, SD=Standard deviation

Table 2 Reliability values (Cronbach's Alpha) for each scale differentiated between pre- and in-service teachers

	Pre-service teachers	In-Service teachers
Control Appraisal	0.61	0.63
Value Appraisal	0.81	0.84
Enjoyment	0.80	0.75
Self-Efficacy	0.90	0.90
TPCK	0.89	0.88

Note. Since all items were equally weighted in the scaling of the test scores, Cronbach's alpha was chosen as the optimal method of estimating reliability (see Malkewitz et al. (2023) for an overview and discussion regarding the appropriateness)

[1] A *t*-test was calculated to analyze differences between pre- and in-service teachers regarding the metric variables age and work experiences. In the case of gender (assessed as categorical variable in the present study), we have claclulated a Chi^2-test.

5.2 Invariance testing

The unrestricted model with freely estimated path coefficients for both groups showed a good model fit (χ^2 = 4.35, *df*=1, *p*=.04; RMSEA=0.12 (0.02; 0.25); CFI=0.98; SRMR=0.02, AIC=5591.31). The restricted model in which path coefficients for pre-service and in-service teachers were set equal yielded a worse model fit than the unrestricted model (χ^2 = 42.89, *df*=25, *p*=.01; RMSEA=0.08 (0.04; 0.12); CFI=0.93; SRMR=0.08, AIC=5596.20). Additionally, the lower AIC score of the unrestricted model indicated that the fully restricted model should be rejected in favor of the unrestricted model. This was further confirmed by the chi-square-difference test for both models (χ^2_{diff} = 39.13, *df*=24, *p*=.03, $\triangle$CFI=−0.05).

The partially restricted model was developed by performing Wald tests to compare all path coefficients across the two groups. Results of the tests are given in Appendix A. The partially restricted model included two freely estimated path coefficients and yielded a good model fit (χ^2 = 25.14, *df*=23, *p*=.34; RMSEA=0.03 (0.00; 0.08); CFI=0.99; SRMR=0.07, AIC=5583.01). The AIC values and the chi-square-difference test (χ^2_{diff} = 21.51, *df*=22, *p*=.49, $\triangle$CFI=0.01) revealed that the unrestricted model with freely estimated coefficients should be rejected in favor of the partially restricted model.

5.3 Final model

The partially restricted model was identified as the comparatively best model to describe the investigated dispositions with respect to the use of ICT as an instructional tool for teaching geometry both for pre-service and for in-service teachers. In the case of pre-service teachers, the model was able to explain 35.6% of the variance of enjoyment, 30.3% of the variance of ICT teaching self-efficacy, and 30.0% of the variance of TPCK. For in-service primary teachers, these values were approximately the same (enjoyment: 34.5%, ICT teaching self-efficacy: 40.0%, TPCK: 25.3%). The results of the standardized path coefficients are presented in Fig. 2. The unstandardized solution is given in Appendix C.

The estimated indirect and total effects are presented in Table 3.

6 Discussion

We consider the investigated dispositions to be inherent constituents of teachers' professional competence to use ICT as an instructional tool for teaching mathematics. All dispositions could be measured reliably and the assumptions of control-value theory (Pekrun, 2006) could be validated for both groups. The results suggest that affective-motivational dispositions regarding the use of ICT for teaching geometry produce a cascade of effects for both pre-service and in-service teachers: proceeding from appraisals of control and value via enjoyment and ICT teaching self-efficacy to the investigated cognitive disposition (i. e technological pedagogical content knowledge). Given that control and value appraisals constitute the beginning of this sequence of effects, they are of particular interest.

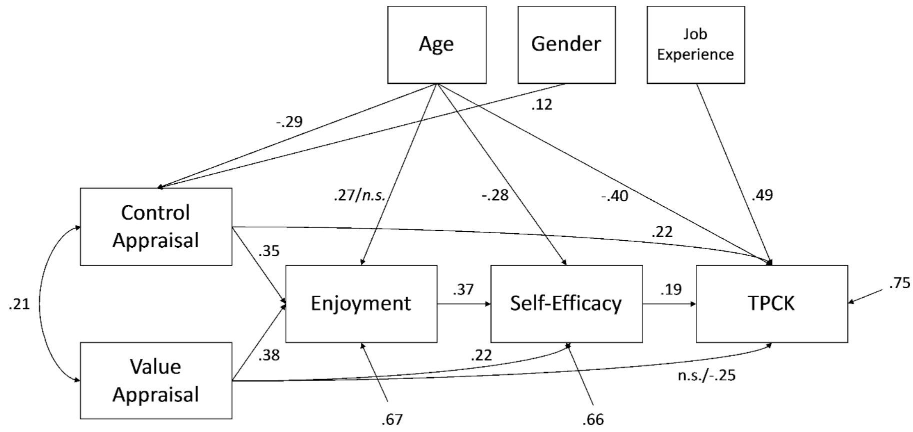


Fig. 2 Final Model (Standardized Solution)

Table 3 Total and indirect effects

Effect	Pre-service teachers	In-service teachers
value → TPCK	total: not significant indirect: not significant	total: not significant indirect: 0.18 (p = .01) via enjoyment and ICT teaching self-efficacy
control → TPCK	total: 0.29 (p < .01) indirect: 0.03 (p = .04) via enjoyment and ICT teaching self-efficacy	
enjoyment → TPCK	total: not significant indirect: 0.07 (p = .02) via ICT teaching self-efficacy	
value → ICT teaching self-efficacy	total: 0.35 (p < .01) indirect: 0.13 (p = .04) via enjoyment	
control → ICT teaching self-efficacy	total: 0.22 (p < .01) indirect: 0.14 (p < .01) via enjoyment	

While value appraisal has an indirect effect on TPCK only for in-service teachers, control appraisal has an indirect effect on TPCK for both groups. This complements and reinforces findings on the importance of control for pre-service mathematics teachers (Jenßen et al., 2021). From the fact that many teachers already consider ICT to be valuable (Fraillon et al., 2019) it can be followed, that interventions should focus first and foremost on improving teachers‘ control appraisal and address and emphasize the value of ICT only subordinately and if necessary.

There are a few but minor differences in the relations between dispositions when comparing pre-service and in-service teachers: A higher age is associated with more enjoyment with respect to the use of ICT only in the case of pre-service teachers.

For in-service teachers a negative effect of value appraisal on TPCK was found, that seems to not exist for pre-service teachers. A possible explanation might be, that in-service teachers perceive themselves as not meeting standards of ICT use in their actual classroom practice more frequently and therefore exhibit lower self-reported knowledge. However, enjoyment and ICT teaching self-efficacy might offset the negative effect overall.

Compared to other studies, our analysis shows almost no gender effects. Only regarding the control appraisal do we find that male participants show a higher level. In contrast, age appears to be more important. A higher age is associated with less control, less ICT teaching self-efficacy, and less self-reported TPCK. The extent to which generational change may be significant here (Orlando & Attard, 2016) is an open question and could be the starting point for future research. For pre-service teachers, higher age is associated with more enjoyment, which could be because this group experiences ICT tools as innovative (and not challenging in a negative way) and/or because they use ICT in the course of their university education more frequently compared to in-service teachers who might lack similar experiences altogether.

The findings of our study are particularly important since opportunities to learn about the use of ICT for teaching primary school mathematics in general, and specifically for teaching geometry in grades 1 to 6, are still rare and the collected evidence provides starting points for the design of seminars and training programs aimed at pre-service and in-service teachers. Studies show that appropriate learning opportunities can change teachers' appraisals and motivation to use ICT for teaching mathematics (Thurm & Barzel, 2020); and although some research hints at the importance of emotions (Reinhold et al., 2021) and enjoyment in particular is known to play a significant role in learning processes (Ainley & Hidi, 2014), the extent to which enjoyment affects teachers' readiness to use ICT for teaching mathematics has not yet been examined.

In Germany most programs aimed to improve teachers' use of ICT for teaching and learning mathematics are designed by teacher educators. In so far as pre-service and in-service teachers do not significantly differ with respect to the relations between investigated affective-motivational and cognitive dispositions, teacher educators need not necessarily differentiate between the two groups in their design of learning opportunities (Aldemir Engin et al., 2022). It might even be worthwhile to consider programs with participants from both groups to take advantage of possible synergistic effects. All affective-motivational dispositions appear to be directly or indirectly relevant to the acquisition of TPCK. Consequently, teacher educators should address control and value appraisals in some form and facilitate the experience of enjoyment to promote ICT teaching self-efficacy and support the acquisition of technological pedagogical content knowledge. It is worth noting, that this implies a need for teacher educators, who know how to provide appropriate technologically supported learning opportunities (Aldemir Engin et al., 2022; Prediger et al., 2019); a requirement that is not easily met as it involves a broad range of skills (Foulger et al., 2017; Krumsvik, 2014).

Although age tends to correlate negatively with control appraisal, ICT teaching self-efficacy and self-reported knowledge, it seems to affect pre-service teachers experience of enjoyment positively. Pointing out the importance of enjoyment for learning processes and providing appropriate emotional support might therefore be an effective means to counterbalance some of the negative effects that were observed in the study. Additionally, it is worth noting, that teachers with more work experience rate their TPCK higher when controlling for age. This hints at practical experience as a teacher being useful in general and might be taken as indication that TPCK is rated higher when pedagogical and/or content knowledge are rated higher due to greater work experience. It might also indicate that working as a teacher provides informal opportunities to learn about the use of ICT as an instructional tool, possibly from colleagues or students. However, this was not assessed in the present study and provides an impetus for future research.

The results of our study must be interpreted against the background of some limitations: First, TPCK was measured through self-reports, mainly because there is no objective measurement instrument available yet. Hence, this concern is not unique to the present study but poses a limitation for research on teachers' TPCK in general (Siddiq et al., 2016). Regarding the quality of the instruments used, it should be noted that the scale for control appraisal showed only acceptable reliability. This could have led to biases in the estimates of all parameters associated with control. The reported results should therefore be treated with caution and further studies are needed to replicate the findings.

Second, the generalizability of our study may be limited in that we did not include unpleasant emotions. Previous studies have shown unpleasant emotions to be relevant for teachers' decisions to use ICT as an instructional tool (Awofala et al., 2019; Yanuarto et al., 2019). The inclusion of unpleasant emotions could therefore lead to a better explanation of variance and future studies might want to include both pleasant and unpleasant emotions to examine differential effects.

Third, our study focused on the use of ICT in geometry and might not be generalizable to mathematics in general (Jenßen et al., 2021) or to other domains. Moreover, as in-service teachers in Germany have little experience in using ICT as an instructional tool (Fraillon et al., 2019), findings of the present study may not be transferable to teachers with a broad experience in teaching with ICT.

Fourth, our study design does not allow for causal inferences or contain assumptions about development of dispositions toward the use of ICT from teacher education to practice. Our study is based on two convenience samples that are not linked to each other.

7 Conclusion

Overall, our study suggests that there are only minor differences between German pre-service and in-service mathematics teachers when considering the relations between affective-motivational and cognitive dispositions to use ICT as an instructional tool for teaching geometry. This result implies that learning opportunities designed to teach and encourage the use of ICT in geometry classes need not differ substantially for pre-service and in-service teachers to be effective. However, intervention studies are needed to confirm causal assumptions and test the effectiveness of specific design features. Nonetheless, the study hints at aspects that are important and should be considered when designing courses, seminars, and training programs for primary grade mathematics teachers. In particular, the findings of our study show the importance of the investigated affective-motivational dispositions (such as beliefs about control and value as well as pleasant emotions like enjoyment) for supporting both pre-service and in-service teachers in developing the professional competence to integrate ICT into their classroom activities.

Additionally, the study validates the assumptions of control-value theory (Pekrun, 2006) for pre-service and in-service teachers with respect to the use of ICT as an instructional tool and indicates a need for further research on the investigated affective-motivational dispositions as variables that affect TPCK.

8 Appendix

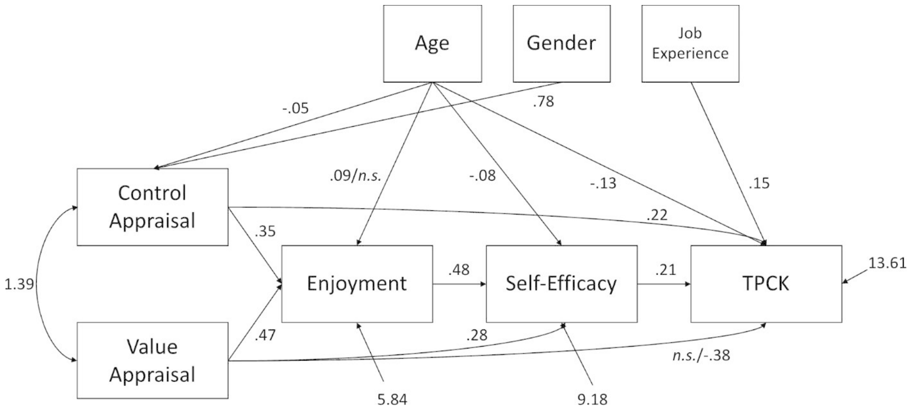
Appendix A Items used in the present study

Scale	Items
TPCK (adapted from Schmidt et al., 2009)	1. I can teach lessons in geometry that appropriately combine technologies and teaching approaches. 2. I can use strategies that combine content, technologies, and teaching approaches that I learned about in my teacher education and training in my geometry class. 3. I can choose technologies that enhance the content for a geometry lesson. 4. I can select technologies to use in my geometry class that enhance what I teach, how I teach, and what students learn. 5. I can teach lessons that appropriately combine geometry, technologies, and teaching approaches.
ICT teaching self-efficacy (adapted from Jenßen et al., 2021)	1. I believe I can use ICT tools in a way that facilitates learning processes in geometry. 2. I am convinced that I can design a digitally supported learning environment for most topics in geometry. 3. I believe I can adequately consider the advantages and disadvantages of an ICT tool when planning a lesson in geometry. 4. I believe that I am able to use ICT tools for teaching geometry in a way that benefits students.
Enjoyment (adapted from Jenßen et al., 2021)	1. I enjoy using ICT tools. 2. I enjoy thinking about possible uses of ICT tools for teaching geometry. 3. I enjoy designing digitally supported learning environments for geometry.
Control appraisal (adapted from Jenßen et al., 2021)	1. It is easy for me to adapt ICT tools to my needs. 2. It is important to me to understand how ICT tools work. 3. It is important to me to be able to modify ICT tools.
Value appraisal (adapted from Jenßen et al., 2021)	1. The use of ICT tools increases the student's motivation for geometry. 2. The use of ICT tools makes it easier to track learning processes in geometry. 3. The use of ICT tools improves the students' understanding of ideas in geometry. 4. The use of ICT tools improves the achievement of students in geometry.

Appendix B Results of the Wald tests per coefficient

Coefficient	*W*	*df*	*p*-Value	Result
control with value	0.96	1	0.33	no significant difference
control → enjoyment	0.88	1	0.35	no significant difference
value → enjoyment	0.72	1	0.40	no significant difference
enjoyment → self-efficacy	0.32	1	0.57	no significant difference
value → self-efficacy	1.11	1	0.29	no significant difference
control → self-efficacy	2.00	1	0.16	no significant difference
self-efficacy → TPCK	0.14	1	0.71	no significant difference
enjoyment → TPCK	1.51	1	0.22	no significant difference
value → TPCK	10.90	1	<0.001	pre-service: not significant; in-service: −0.25
control → TPCK	1.05	1	0.31	no significant difference
age → control	1.73	1	0.18	no significant difference
job → control	0.08	1	0.77	no significant difference
gender → control	0.14	1	0.71	no significant difference
age → value	0.09	1	0.77	no significant difference
job → value	0.05	1	0.82	no significant difference
gender → value	0.04	1	0.84	no significant difference
age → enjoyment	13.44	1	<0.001	pre-service: 0.27; in-service: not significant
job → enjoyment	1.01	1	0.31	no significant difference
gender → enjoyment	0.04	1	0.84	no significant difference
age → self-efficacy	1.22	1	0.27	no significant difference
job → self-efficacy	2.50	1	0.11	no significant difference
gender → self-efficacy	1.80	1	0.18	no significant difference
gender → TPCK	1.36	1	0.24	no significant difference
age → TPCK	2.87	1	0.09	no significant difference
job → TPCK	0.01	1	0.99	no significant difference

Appendix C Unstandardized solution of the final model



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Declarations

Conflict of interest All authors declare that they have no conflicts of interest.

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Authors and Affiliations

Lars Jenßen[1] · Katja Eilerts[2] · Frederik Grave-Gierlinger[2]

✉ Lars Jenßen
lars.jenssen@hu-berlin.de

Katja Eilerts
katja.eilerts@hu-berlin.de

Frederik Grave-Gierlinger
frederik.gierlinger@hu-berlin.de

1 Department of Education Sciences, Humboldt-Universität zu Berlin, Berlin, Germany

2 Primary Mathematics Education, Humboldt-Universität zu Berlin, Berlin, Germany