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Exploring factors influencing pre-service teacher's digital teaching competence and the mediating effects of data literacy: empirical evidence from China

Juan Chu[1], Ruyi Lin[1], Zihan Qin[1], Ruining Chen[1], Ligao Lou[1]✉ & Junfeng Yang[1]✉

The development of pre-service teachers' digital teaching competence is crucial for effectively infusing technology into teaching. With the growing importance of data in education, it is imperative to explore the influencing factors of digital teaching competence and the potential role of data literacy in facilitating competence. Thus, this study focused on investigating the factors influencing pre-service teachers' digital teaching competence, namely technology attitudes, technology operations, technology ethics, and data literacy. Additionally, it examined the potential effect of data literacy on digital teaching competence. The study involved 244 Chinese pre-service teachers, and a Structural Equation Model (SEM) was created using SPSS and SmartPLS for analysis. The findings highlighted that technology attitudes, technology ethics, and data literacy directly influenced pre-service teachers' digital teaching competence. Data literacy fully mediated the relationship between technology operations and digital teaching competence, and partially mediated the relationships between technology attitudes and digital teaching competence, as well as between technology ethics and digital teaching competence. Moreover, technology ethics acted as a partial mediator between technology attitudes and both digital teaching competence and data literacy. These results indicated that fostering positive technology attitudes, technology operations, and technology ethics could enhance pre-service teachers' data literacy and improve their digital teaching competence.

[1] Jing Hengyi School of Education, Hangzhou Normal University, Hangzhou, China. ✉email: loulg@hznu.edu.cn; yjf@hznu.edu.cn

Introduction

The successful incorporation of information technology into teaching has been a prevalent topic in the field of teacher education for many years. As pre-service teachers occupy a dual role as students and future teachers, they require digital competence and teaching competence to facilitate active integration into the digital society (Instefjord and Munthe, 2017). Lim (2023) emphasized that pre-service teacher education was a crucial factor in developing the competence of future teachers. As a vital resource for the development of future teachers, the digital teaching proficiency of pre-service teachers plays a vital role in determining the quality of future education (Yan et al., 2018). Despite having a favorable impression of digital competence, pre-service teachers may not have acquired sufficient proficiency to enhance the teaching process (Tárraga-Mínguez et al., 2021). Therefore, sustainable development of digital teaching competence for pre-service teachers is crucial.

INTEF (2017) defined digital teaching competence as "a set of competencies that teachers in the 21st century must acquire to improve the efficiency of educational practice and ensure continuous professional development". Enhancing teachers' digital teaching competence contributed to the digital transformation of schools (Hämäläinen et al., 2021), the development of students' digital competence (Esteve-Mon et al., 2020; Llopis et al., 2021), and ongoing professional skill development for teachers (Cazco et al., 2016). However, studies have found that despite their digital competence, pre-service teachers may still lack the ability to implement digital tools effectively in the teaching process.

The sustainable development of pre-service teachers' digital teaching competence should be promoted; it is essential to have a thorough understanding of the factors that influence the deployment of training programs. Current research indicates that various factors, broadly classified as external environmental factors and teachers' characteristics, influence the digital teaching competence of teachers (Tezci, 2011). The influencing factors of the external environment encompassed school climate and support (Demiraslan and Usluel, 2008), and facilitating conditions (Teo et al., 2008, 2009). In contrast, personal factors included technology attitudes (Gurer, 2021), technology competencies (Tondeur et al., 2018), data literacy (Lin et al., 2022), and technology ethics (Guillén-Gámez et al., 2021), among others. Researchers have conducted limited studies on how data literacy and technology ethics affect the pre-service teacher's digital teaching competence, with technology attitudes and technology operations variables often used to investigate the relationships with digital teaching competence. Hence, this study regards technology attitudes, technology operations, technology ethics, and data literacy as variables that potentially affect the pre-service teacher's digital teaching competence.

In modern education, data is gaining importance as a tool to enable teachers to make informed decisions, and it has become crucial in preparing future educators (Reisoğlu and Çebi, 2020). Nevertheless, the ability to analyze data alone is insufficient to improve instruction and meet students' needs (Shepard et al., 2018), and teachers must possess data literacy, which would allow them to make informed decisions based on a deep understanding of data, promptly diagnose the quality of teaching, and adjust both the student's learning and teaching methodologies as needed (Ball et al., 2008). A growing body of research suggested the crucial role of data literacy in successfully integrating information and communication technology into the instruction of pre-service teachers (McDowall et al., 2021). Only the study conducted by Lin et al. (2022) substantiated that teachers' data literacy had a significant impact on the digital teaching competence of teachers. Further research is needed to establish more evidence and explore the relationship between data literacy and the digital teaching competence of future teachers to guide teacher training programs better. Additionally, little attention has been given to training teachers on data literacy during teacher training (Mandinach et al., 2015). Previous research highlighted technology attitudes and operations as variables that influence the data literacy of pre-service teachers (Miller-Bains et al., 2022). The emergence of a new generation of AI assistants, such as ChatGPT, has heightened attention to a range of ethical concerns and their expanding impact over time. Teachers must adhere to ethical standards when utilizing digital technology to promote the healthy development of their students. No studies have explored the impact of technology ethics as a variable affecting data literacy. Thus, this study includes technology attitudes, technology operations, and technology ethics as variables that could influence the data literacy of pre-service teachers.

To sum up, this study has identified technology attitudes, technology operations, technology ethics, and data literacy as variables that potentially influence the pre-service teacher's digital teaching competence. Additionally, researchers selected technology attitudes, operations, and ethics as variables that could impact pre-service teachers' data literacy. Data literacy may be a mediating factor in this study. As such, this paper presents and explores the results of the analysis of mediating variables in the data analysis process.

Literature review and hypotheses development

Technology attitudes. In this study, technology attitudes refer to teachers' general support or opposition toward using digital technologies in the classroom. Attitudes had three components: cognitive, emotional, and behavioral (Smith, 1968). Firstly, Mandinach and Gummer (2013) found that pre-service teachers often need to be aware of the data's significance and potential benefits; they could not use it effectively (Merk et al., 2020). Consequently, cultivating positive technology attitudes could positively impact data literacy (Dunn et al., 2013). Secondly, previous research demonstrated a clear link between technology attitudes and operations (Scherer et al., 2018; Teo et al., 2008, 2009). Specifically, Teo et al. (2008, 2009) found that the success of technology implementation in educational programs was highly dependent on the attitude and support of teachers and that technology attitudes could significantly affect teachers' ICT skills development (Wang and Zhao, 2021), thus, it could be largely concluded that having positive technology attitudes can enhance technology operations outcomes. Thirdly, despite growing concerns about the ethical implications of digital competency development, pre-service teachers received limited moral training in this era. As a result, researchers emphasized the importance of attending to ethical issues related to technology use (Ki and Ahn, 2006). Based on these findings, it seems reasonable to suggest that technology attitudes can contribute to more technology ethics practices. Lastly, Han et al. (2017) demonstrated that technology attitudes could hinder the integration of ICT in the classroom (Sang et al., 2011). Further, Valtonen et al. (2017) found that attitudes could influence teaching behavior and the use of digital technologies during instruction (Aslan and Zhu, 2017). Moreover, other research has indicated that there may not be a significant relationship between teachers' technology attitudes, as reported by Ndibalema (2014), and their level of digital teaching competence. These findings suggest that while technology attitudes play a role in digital teaching competence, the relationship between these factors may not always be straightforward.

This study builds upon previous research and explores the relationship between technology attitudes and data literacy, technology operations, technology ethics, and digital teaching competence. Furthermore, our examination of the relationship between technology attitudes, ethics, and operations presents a novel contribution to the field.

Technology operations. The present study introduces the concept of technology operations, which encompasses pre-service teachers' ability to use ICT hardware and software tools effectively to enhance the teaching process. As Goktas et al. (2009) noted, teachers must possess sufficient technology competence in education. Despite extensive efforts by many countries and international organizations to enhance teachers' technology competence, various studies demonstrate that the level of technical competencies among teachers remains unsatisfactory (Gudmundsdottir and Hatlevik, 2018; Røkenes and Krumsvik, 2014; Valtonen et al., 2015). On the one hand, proficiency in hardware and software tools is critical in maximizing the value of teaching data. Individuals with solid technology operations were generally more adept at data literacy (Ng, 2012). One could propose that technology operations positively impact data literacy outcomes. On the other hand, Garcia et al. (2013) and Cazco et al. (2016) found that teachers who prioritize the development of software and hardware operations skills tended to have a moderately high level of digital teaching competence. Furthermore, Ghavifekr and Rosdy (2015) suggested incorporating digital tools could enhance teaching efficiency (Hatlevik and Hatlevik, 2018). However, other studies highlighted the importance of additional factors in promoting digital teaching competence beyond technology operations alone (Mouza et al., 2014; Cabero-Almenara et al., 2021a; Sánchez-Caballé and Esteve-Mon, 2022). In light of these findings, it is reasonable to infer that technology operations can positively impact digital teaching competence but may not be the only determining factor.

In short, previous studies have primarily relied on intuitive and experiential perspectives to conclude that technology operations significantly impact data literacy and digital teaching competence. Still, few empirical studies have yet to explore this impact. This article provides empirical evidence to supplement these conclusions.

Technology ethics. In this research, technology ethics (TE) is defined as a set of ethical guidelines and legal standards that instructors are expected to follow when using various technological tools in the classroom for teaching and learning purposes. In recent years, the ethical concerns surrounding educational technology have come to the forefront of discussions in the field (Baum, 2005). Moreover, new ethical issues are emerging with integrating artificial intelligence technology, such as ChatGPT, into the educational landscape. The unethical use of technology in education was a significant problem noted by Ki and Ahn (2006). Ethics was one of the four factors identified in the TRACK depth scale, alongside design, exertion, ethics, and proficiency (Kabakci Yurdakul and Çoklar, 2014). In light of the growing importance of ethical considerations in educational technology, future teacher training should prioritize the development of moral competence (Mâță et al., 2020). Teachers will play a crucial role in teaching students not only how to maximize the value of data to support their learning but also how to handle data privacy and security concerns the future (Krutka et al., 2019; Milton et al., 2021; Vartiainen et al., 2022). Technology ethics could impact all competencies that students acquire through the teaching-learning process (Novella-García and Cloquell-Lozano, 2021), affect the handling and manipulation of data (Nordkvelle and Olson, 2005), and significantly predict pre-service teachers' problem-solving ability (Ersoy et al., 2016). In light of this, there is reason to believe that technology ethics may positively impact data literacy and digital teaching competence.

In conclusion, previous research has yet to explore the importance of ethics in teacher professional development. As technologies such as artificial intelligence pose challenges to human society, there is an increasing need for awareness, knowledge, and behavior related to ethics. Deng and Zhang (2023) developed and validated the TPCEK scale based on TPACK, which was used to evaluate pre-service teachers. This study is one of the few that explores the relationship between technology ethics and data literacy and the relationship between technology ethics and digital teaching competence.

Data literacy. The concept of data literacy was first proposed by Gilster (1997). Mandinach and Gummer (2013) defined data literacy as understanding and applying data in making informed decisions. Lin et al. (2022) proposed four critical steps to the data processing cycle: data collection, data analysis, data evaluation, and data application. According to Kippers et al. (2018), data literacy entailed setting a clear objective, collecting relevant data, analyzing it effectively, interpreting the results, and making informed decisions. Gisbert-Cervera et al. (2022) noted that pre-service teachers' data literacy should prioritize during university training. Moreover, a lack of data literacy early in an instructor's career could pose a significant obstacle to achieving a high level of digital teaching competence (Davis and Jones, 2022; Halverson, 2010). Data-driven teaching has revolutionized classroom practice and optimized student learning (Miller-Bains et al., 2022). Nevertheless, empirical studies on relevant research still need to be extensive, with more theoretical assumptions (Cowie and Cooper, 2017). Given these studies, it is acceptable to assume that data literacy can positively affect digital teaching competence. Additionally, previous studies identified a correlation between technology attitudes and data literacy (Datnow and Hubbard, 2016). Ethics and morality were recognized as fundamental principles in using digital media (Ata and Yıldırım, 2019). Technology operations have also been seen as a variable significantly predicting data literacy; however, evidence was limited (Ng, 2012). Thus, this study aims to investigate the mediating effect of data literacy.

Research model. This study investigates the factors that impact digital teaching competence based on a literature review. Furthermore, the study explores the mediating effect of data literacy in the relationship between technology attitude, technology operations, technology ethics, and digital teaching competence. In summary, the research model (Fig. 1) depicts the testing of ten hypotheses in this study. The figure illustrates the direct impact of technology attitudes, technology operations, technology ethics, and data literacy on digital teaching competence and the indirect influence of data literacy on digital teaching competence.

Methods

Participants. Between 2021 and 2022, this study disseminated a digital teaching competence questionnaire to pre-service teachers at a Normal University in Hangzhou, Zhejiang Province, China. We used the online questionnaire platform, Wenjuanxing (https://www.wjx.cn/), to collect the data resulting in 244 valid responses. We informed the participants that the data would only be used for research purposes and that no personally identifiable information would be disclosed.

A total of 244 pre-service teachers participated in this investigation, with 130 participants in 2021 and 114 participants in 2022. Both exploratory and confirmatory factor analyses were utilized with distinct data sets to ensure the robustness of the

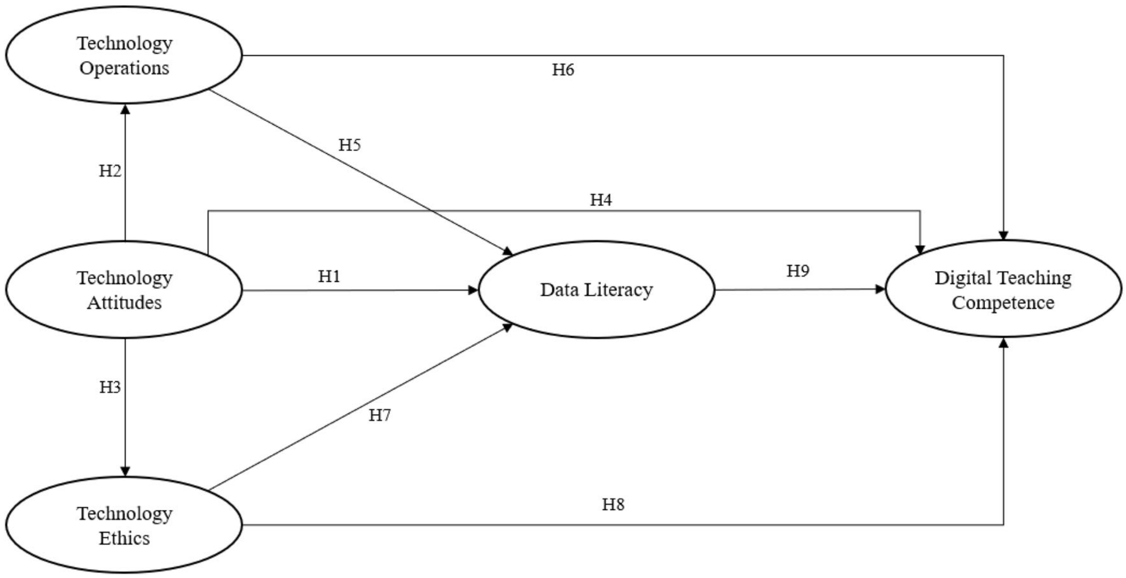

Fig. 1 The proposed research model. Hypothesis 1: Technology Attitudes have a positive effect on Data Literacy. Hypothesis 2: Technology Attitudes have a positive effect on Technology Operations. Hypothesis 3: Technology Attitudes have a positive effect on Technology Ethics. Hypothesis 4: Technology Attitudes have a positive effect on Digital Teaching Competence. Hypothesis 5: Technology Operations have a positive effect on Data Literacy. Hypothesis 6: Technology Operations have a positive effect on Digital Teaching Competence. Hypothesis 7: Technology Ethics has a positive effect on Data Literacy. Hypothesis 8: Technology Ethics has a positive effect on Digital Teaching Competence. Hypothesis 9: Data Literacy has a positive effect on Digital Teaching Competence. Hypothesis 10: Data Literacy acts as a mediator between technology attitudes, technology operations, technology ethics, and Digital Teaching Competence.

Table 1 Demographic profile of respondents.

Demographic profile		Frequency	Percentage (%)
Gender	Male	44	18.0%
	Female	200	82.0%
Grade Level	Freshman	0	0%
	Sophomore	115	47.1%
	Junior	129	52.9%
	Senior	0	0%
Whether you have taken or are taking the Fundamentals of Computing course or a related course	Yes	129	52.9%
	No	115	47.1%

findings. Specifically, 130 data points were used for exploratory factor analysis (EFA) in 2021. Subsequently, after validating the instrument, 114 data points from 2022 were selected for confirmatory factor analysis (CFA) to develop structural equation models. Table 1 summarizes the demographic details of the 244 participants included in this investigation.

Instrument. The instrument was composed of two sections. The first section requested demographic information, including gender, grade level, major, and whether you have taken or are taking the Fundamentals of Computing course or a related course. The second section comprises five dimensions: Technology Attitudes, Technology Operations, Technology Ethics, Data Literacy, and Digital Teaching competence. The items in several scales had been slightly modified. The exploratory factor analysis (EFA) identified 19 items across these dimensions, including Technology Attitudes (3 items), Technology Operations (3 items), Technology Ethics (3 items), Data Literacy (5 items), and Digital Teaching competence (5 items). Each item was evaluated by a five-point Likert scale, ranging from 1 = "strongly disagree" to 5 = "strongly agree." Table 2 provides a detailed discrimination of the rankings and their relevant citations.

Results

The data collected were analyzed using SPSS version 26 and SmartPLS version 3. SPSS version 26 was used to analyze the data for exploratory factor analysis and demographic analysis, which identified five dimensions: Technology Attitudes, Technology Operations, Technology Ethics, Data Literacy, and Digital Teaching Competence. Subsequently, SmartPLS was used to conduct a confirmatory factor analysis, evaluate the measurement model, test the suggested structural equation model, and explore the mediating influences in the structural equation model.

Exploratory factor analysis. To explore the dimensional composition of the questionnaire, this study conducted an exploratory factor analysis on 130 data from 2021. Factor analysis was utilized to determine the linkage between items under the premise that such a link exists. The Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity were used to assess whether there were sufficient data for the factor analysis. The survey findings yielded a KMO test value of 0.929, indicating good data for factor analysis.

Exploratory factor analysis was subsequently conducted. The results are presented in Table 3, which showed that the KMO test value of the survey results was 0.880, exceeding 0.7. Bartlett's test of sphericity yielded a significance probability value of 0.000 ($p < 0.01$), indicating the presence of common factors, a validity structure, and interconnectedness between variables in the questionnaire. These findings suggested that the collected data were appropriate for factor analysis.

The principal component analysis approach was used to evaluate the structural validity of the data during the factor analysis procedure. The factor load matrix was rotated by applying the maximum variance method. We utilized a fixed 5-factor extraction criterion when the first eigenvalue was more

Table 2 Sources of indicators.

Constructs	Indicators	Sources
TA	TA1—I am aware of the significance of the application of digital technology in contemporary education. TA2—I actively monitor the implementation and growth of digital technology in education. TA3—I am eager to share my digital technology application experience and findings with coworkers.	Schmidt et al. (2009); Taylor (2004); Redecker (2017); Lin et al. (2022)
TO	TO1—I can troubleshoot common issues with multimedia teaching equipment applications. TO2—I use digital teaching equipment proficiently in the classroom (e.g., computers, projectors, visualizers). TO3—I am proficient with at least one discipline-specific teaching tool (e.g., geometer sketchpad, online maps, and realistic experiments).	Schmidt et al. (2009); Archambault and Crippen (2009)
TE	TE1—When citing the work of others, I always indicate the source of information. TE2—I actively foster a healthy and civilized communication environment and do not disseminate misleading, pornographic, violent, or other inappropriate material. TE3—I am legally aware of technology security and suitable handling procedures for potential safety threats, and I do not illegally access others' information.	McGarr and McDonagh (2021); Cabero-Almenara et al. (2021b); Reisoğlu and Çebi (2020)
DL	DL1—I can discover new data and perceive crucial facts in time. DL2—I rapidly obtain and access teaching-related raw data (e.g., access to data and databases). DL3—I utilize the software for statistical analysis to handle and evaluate the received data (e.g., SPSS, Excel). DL4—I evaluate the data's source, gathering technique, and quality to assure data accuracy. DL5—I analyze data to assist instructional decisions and enhance teaching tactics.	Papamitsiou et al. (2021); Reeves and Honig (2015); Mandinach and Gummer (2016)
DTC	DTC1—I can use technological tools to create digital instruction resources that enhance teaching. DTC2—I can handle digital instruction resources following backup, sharing, and collaboration demands. DTC3—I can utilize technological tools to extract and summarize teaching content. DTC4—I can select the appropriate instructional media and resources for various process steps. DTC5—I can employ instructional media to optimize teaching at different stages of the instructional process.	Tondeur et al. (2016); Zhao et al. (2021); Avidov-Ungar and Iluz (2014)

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, *DTC* digital teaching competence.

Table 3 KMO and Bartlett's test of sphericity.

Kaiser-Meyer-Olkin measure of sampling adequacy		0.880
Bartlett's Test of Sphericity	Approx. Chi-Square	1869.528
	df	171
	Sig.	0.000

significant than 1. We excluded items with either too low loads (<0.3) or multiple loads.

Ultimately, after considering all factors, we extracted five common elements. The cumulative total variance interpretation rate of these five factors was 78.29%, indicating that the extracted factors were sufficient to explain over 78.29% of the variation in all items, which suggests that the extracted factors were satisfactory in their ability to explain the variance in the data.

Assessing the measurement model. AVE (average variance extracted) was helpful for assessing convergent and divergent validity. Some researchers stipulated that AVE values in the reflective model should be at least 0.5 (Chin, 1998; Höck and Ringle, 2006). Composite reliability (CR), ranging from 0 to 1, was used as another indicator of convergent validity. CR values should be at least 0.6 in the reflective model. Cronbach's alpha, a measure of internal consistency reliability that ranges from 0 to 1, was introduced by Cronbach (1951). A higher value of Cronbach's alpha, closer to 1, indicated higher measurement reliability. There were varying recommendations for acceptable values of Cronbach's alpha, ranging from 0.70 to 0.95 (Bland and Altman, 1997; DeVellis and Thorpe, 2021). The importance of AVE, CR, and Cronbach's alpha are presented in Table 4.

Table 4 AVE and reliability measures.

Constructs	AVE	Composite reliability	Cronbach's alpha
DL	0.815	0.957	0.943
TA	0.782	0.915	0.861
TE	0.695	0.872	0.784
TO	0.729	0.889	0.814
DTC	0.735	0.932	0.909

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, DTC digital teaching competence.

Fornell and Larcker (1981) proposed that the square root of AVE should be greater than any other correlation involving a construct as a criterion for assessing discriminant validity. Wong et al. (2016) corroborated this criterion and demonstrated its reliability. The square root of AVE values for the current study are shown in Table 5.

Cross-loading refers to the degree to which an indicator relates to multiple latent variables. It reflected the contribution of an

Table 5 The discriminant validity.

	DL	TA	TE	TO	DTC
DL	***0.903***				
TA	0.614	***0.884***			
TE	0.542	0.505	***0.833***		
TO	0.548	0.353	0.267	***0.854***	
DTC	0.825	0.656	0.603	0.495	***0.857***

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, *DTC* digital teaching competence.
The square root of AVEs is presented diagonally in bold and italics, while the correlation between constructs is shown as the non-diagonal elements.

Table 6 The indicators' loading and cross-loading values.

	DL	TA	TE	TO	DTC
DL1	0.902	0.599	0.590	0.467	0.832
DL2	0.922	0.572	0.492	0.538	0.724
DL3	0.842	0.468	0.408	0.443	0.626
DL4	0.923	0.540	0.452	0.486	0.734
DL5	0.921	0.577	0.485	0.537	0.785
TA1	0.539	0.859	0.461	0.198	0.543
TA2	0.517	0.908	0.412	0.370	0.547
TA3	0.570	0.885	0.466	0.361	0.641
TE1	0.573	0.499	0.870	0.336	0.588
TE2	0.286	0.336	0.741	0.053	0.358
TE3	0.437	0.401	0.882	0.213	0.518
TO1	0.530	0.353	0.332	0.923	0.475
TO2	0.323	0.265	0.075	0.760	0.332
TO3	0.519	0.281	0.232	0.871	0.444
DTC1	0.746	0.664	0.564	0.502	0.903
DTC2	0.770	0.610	0.508	0.455	0.905
DTC3	0.721	0.505	0.490	0.309	0.829
DTC4	0.534	0.362	0.399	0.541	0.764
DTC5	0.733	0.619	0.600	0.348	0.877

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, *DTC* digital teaching competence.

Table 7 The HTMT criterion.

	DL	TA	TE	TO	DTC
DL					
TA	0.677				
TE	0.597	0.599			
TC	0.611	0.416	0.319		
DTC	0.879	0.725	0.686	0.578	

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, *DTC* digital teaching competence.

indicator to other constructs; hence the term "cross" and cross-loadings should be greater than factor loadings (Fornell and Larcker, 1981). The factor loadings and cross-loading values for the indicators are shown in Table 6.

In addition to cross-loading, Henseler et al. (2015) proposed HTMT as an indicator of discriminant validity, which was considered poor if it exceeded 0.90 (Gold et al., 2001). The values of HTMT for the current study are presented in Table 7. Based on the analysis results, we have established a robust measurement model in this study.

Examining the structural model. To determine the significance of the relationship between the independent and dependent variables in this study, we conducted 5000 bootstrap samples.

Table 8 Result of structure model examination.

Hypotheses	Paths	Path coefficients (β)	t-values	Remarks
H1	TA → DL	0.353*	2.466	Supported
H2	TA → TO	0.353**	2.748	Supported
H3	TA → TE	0.505 ***	5.505	Supported
H4	TA → DTC	0.189*	2.173	Supported
H5	TO → DL	0.351**	3.030	Supported
H6	TO → DTC	0.065^{NS}	0.904	*Unsupported*
H7	TE → DL	0.270**	2.987	Supported
H8	TE → DTC	0.177**	2.598	Supported
H9	DL → DTC	0.578***	6.804	Supported

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, *DTC* digital teaching competence.
$^{NS}p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

The PLS-SEM analysis revealed that TA had a significant impact on DL ($\beta = 0.353$; $p < 0.05$), TO ($\beta = 0.353$; $p < 0.01$), TE ($\beta = 0.505$; $p < 0.001$), and DTC ($\beta = 0.189$; $p < 0.05$), providing statistical support for four hypotheses (H1, H2, H3, and H4). Moreover, TO significantly influenced DL ($\beta = 0.351$; $p < 0.01$) but had no significant effect on DTC ($\beta = 0.065$; $p > 0.05$). The analysis results supported hypothesis 5, but H6 was not supported. The study showed that TE had significant effects on DL ($\beta = 0.270$; $p < 0.01$) and DTC ($\beta = 0.177$; $p < 0.01$), supporting the two hypotheses (H7 and H8). Additionally, DL was found to significantly influence DTC ($\beta = 0.578$; $p < 0.001$), supporting Hypothesis 9.

A comprehensive presentation of the bootstrap results is provided in Table 8 and Fig. 2.

Predictive relevance. The coefficient of determination (R^2) indicates a model's predictive accuracy level. R^2 values ranged between 0 and 1, with lower values indicating lower explanatory power and higher values indicating better explanatory power. Hair et al. (2021) established criteria for interpreting R^2 value, whereby values of 0.75 were considered substantial, 0.50 were moderate, and 0.25 were weak. Table 9 shows the importance of R^2, DL (0.556, medium), TE (0.255, weak), TO (0.125, weak), and DTC (0.739, substantial). Overall, the data in this study exhibited moderate levels of predictive accuracy.

In addition to R^2, Stone-Geisser's Q^2 statistics were also used to evaluate the predictive validity of a model. The value of Q^2 could be classified into trim (0.02), medium (0.15), and significant (0.35) levels (Wong et al., 2015). Table 9 presented Q^2 values for all four endogenous structures, and it was evident that all of the Q^2 values were above 0, indicating significant predictive validity for the model.

Inspecting the mediating effects. Based on the finding that technology operations did not significantly impact digital teaching competence, we hypothesized that data literacy might act as a mediator for H6 and conducted a mediation analysis (Hew et al., 2017), the results are presented in Table 10. According to Hair et al. (2014), full or partial mediation was conditional on the indirect effects between the exogenous structure and the endogenous structure through the mediating design being statistically significant.

Complete mediation occurred when VAF > 80%, partial mediation occurred when 20% < VAF < 80%, and no mediation occurred when VAF < 20%. VAF (Variance Account For) refers to the percentage of indirect effects on the total impact and could

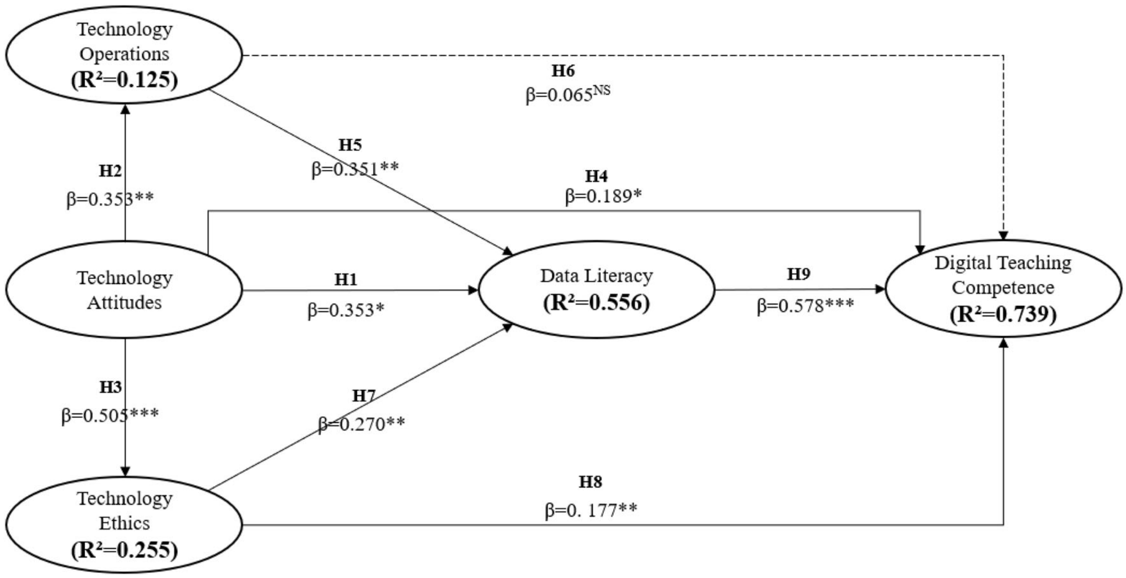

Fig. 2 Result of structure model examination. Note: →Significant Path; ⇢Insignificant Path. $^{NS}p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 9 Predictive accuracy and predictive relevance.

Endogenous constructs	R^2	Q^2
DL	0.556	0.434
TE	0.255	0.164
TO	0.125	0.081
DTC	0.739	0.522

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, *DTC* digital teaching competence.

be calculated as follow:

$$VAF = \frac{a*b}{a*b+c}$$

Table 10 showed that data literacy partially mediated the path between technology attitudes and digital teaching competence, as well as between technology ethics and digital teaching competence. Data literacy fully mediates the way between technology operations and digital teaching competence. Surprisingly, the results revealed that technology ethics played a complementary, partially mediating role in the path between technology attitudes and data literacy and between technology attitudes and digital teaching competence, which is an intriguing finding that warrants further investigation.

Discussion

Summary of findings. This study aimed to investigate the factors that impact the pre-service teacher's digital teaching competence, while also exploring the mediating effect of data literacy. The findings demonstrated that technology attitudes, ethics, and data literacy could significantly predict pre-service teachers' digital teaching competence. Moreover, data literacy was found to mediate the relationship between technology attitudes and digital teaching competence, the relationship between technology operations and digital teaching competence, and the relationship between technology ethics and digital teaching competence. These results are discussed in more detail below.

Firstly, this study has discovered a substantial direct impact of pre-service teachers' technology attitudes on their digital teaching competence, as well as their technology ethics and data literacy, supporting hypotheses H4, H8, and H9. These findings are consistent with prior research. Sang et al. (2011) found that primary teachers who exhibit positive technology attitudes in education were likelier to integrate ICT into their teaching practices. In line with this, Novella-García and Cloquell-Lozano (2021) highlighted the importance of ethics in teacher education for cultivating digital competence. Similarly, Lin et al. (2022) demonstrated that teachers' data literacy could significantly impact their digital teaching competence. Based on these findings, it is crucial to motivate pre-service teachers' attitudes towards using technology in teaching, pay close attention to and protect students' data privacy in the classroom, promptly address technology ethics concerns, and enhance their data literacy to improve their digital teaching competence. These steps are essential to equip pre-service teachers with the necessary skills and knowledge to effectively integrate technology into their teaching practices, all while ensuring a safe, ethical, and data-sensitive learning environment for their students. To cultivate future educators' digital teaching competence, university instructors must highlight the importance of attitudes in designing an effective curriculum and act as positive role models for pre-service teachers. Deliberate attention should be given to integrating ethical knowledge and skills throughout technology-oriented courses, enabling pre-service teachers to develop ethical technology usage habits and become responsible digital citizens. Additionally, data should be effectively utilized to enhance pre-service teachers' data literacy, enabling them to communicate with data and make informed decisions based on evidence.

Secondly, this study has revealed an unexpected result, as H6 is not supported. Contrary to the hypothesis, the findings indicate that pre-service teachers' technology operations do not have a direct impact on their digital teaching competence. The finding differs from the research conducted by Hatlevik and Hatlevik (2018), as their study suggested that successful integration of ICT in education relied on teachers' readiness to use technological tools. Nonetheless, while young people possess strong competence in operating digital devices, using this competence was limited due to being in the initial stage of professional development. In light of this finding, the conclusion that technology operations are not significantly associated with digital teaching competence also appears reasonable. After all, the development of digital teaching competence involves more than mere technology operations, as it occurs within the context of the

Table 10 Mediation test.

Paths	Indirect effects	*t*-values	Direct effects	*t*-values	VAF	Remarks
TA to DL via TE	0.136**	2.917	0.353*	2.425	27.8%	Complementary partial mediation
TA to DL via TO	0.124^{NS}	1.576	0.353*	2.466	0%	*Without mediation*
TA to DTC via TE	0.090*	2.270	0.189*	2.173	32.3%	Complementary partial mediation
TA to DTC via TO	0.023 ^{NS}	0.739	0.189*	2.173	0%	*Without mediation*
TA to DTC via DL	0.204*	2.107	0.189*	2.173	51.9%	Complementary partial mediation
TO to DTC via DL	0.203**	2.580	0.065^{NS}	0.904	100.0%	Full mediation
TE to DTC via DL	0.156***	3.295	0.177**	2.598	46.8%	Complementary partial mediation

TA technology attitudes, *TO* technology operations, *TE* technology ethics, *DL* data literacy, *DTC* digital teaching competence.
$^{NS}p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

field of education. Equipment and tool operations are insufficient in teaching, as specific education and teaching knowledge—including teaching design ability and experience—are necessary. Therefore, teachers' training programs must place equal emphasis on pedagogical skills and technology operations.

Thirdly, this study has proved that technology attitudes strongly impacted pre-service teachers' data literacy, technology operations, and technology ethics, supporting hypotheses H1, H5, and H7. These findings are in line with previous studies. Teachers, who have a positive attitude towards technology, are equipped with skilled technical operations, and have a keen sense of technology ethics, are more likely to use student performance data to make decisions (Knezek and Christensen, 2016; Rubach and Lazarides, 2021). Pre-service teachers play the dual roles of students and future teachers. It is crucial to develop their data literacy and data literacy for prospective students to cultivate digital citizenship in society. This study shows that pre-service teachers' data literacy could be effectively promoted by fostering positive technology attitudes, teaching technology operations, and cultivating technology ethics. Instructors could enhance data literacy by creatively utilizing pre-service teachers' classroom performance and behavior data to foster their enthusiasm and initiative in using data. Furthermore, instructing pre-service teachers on using software and hardware can help them to use data and make informed decisions, experiencing the use of data and its convenience in teaching. Additionally, instructors should provide ethical education regarding responsible data use, including data utilization limitations and anonymization practices, to cultivate ethical behavior in applying technology.

Fourthly, this study has concluded that technology attitudes had a strong direct impact on pre-service teachers' technology operations. At the same time, technology attitudes substantially directly affected pre-service teachers' technology ethics. Hence, H2 and H3 are supported. These results coincide with previous studies. Aslan and Zhu (2017) found that it was easier if teachers had a positive attitude toward using technology in teaching. They would ignore ethical issues in the classroom. After all, attitudes had three components: cognitive, emotional, and behavioral (Svenningsson et al., 2022). Hence, encouraging pre-service teachers to incorporate technology into classroom activities is paramount. To achieve this, university instructors should create an environment that promotes positive attitudes and motivation toward using technology in teaching. By comprehensively utilizing technology tools, pre-service teachers could be aware of the benefits technology can offer in enhancing the teaching process, encouraging teachers' professional development, and enhancing student growth, enabling them to become adept at using technology to teach and stimulating their enthusiasm for doing so.

Fifthly, this study has unveiled that data literacy played a dual role in mediating the relationship between pre-service teachers' technology attitude or technology ethics and their digital teaching competence. More specifically, data literacy is a complementary partial mediator between technology attitudes and digital teaching competence while functioning as a full mediator between technology operations and digital teaching competence. First, previous research highlighted two critical associations between pre-service teachers' technology attitudes and data literacy and the importance of data literacy for digital teaching competence. Second, previous research identified the link between pre-service teachers' technology operations and data literacy and the importance of data literacy to digital teaching competencies. Third, previous research identified the relationship between pre-service teachers' technology ethics and data literacy and the importance of data literacy to digital teaching competence. Based on previous research and echoed those findings, this study confirmed that data literacy could mediate the development of pre-service teachers' digital teaching competence. Hence, pre-service teachers, who exhibit a positive attitude toward technology, possess advanced technology operations, and have a deeper understanding of technology ethics are likelier to have an elevated level of data literacy.

Finally, this study has revealed an exciting relationship with technology ethics as a crucial complementary partial mediator between technology attitude and data literacy, or digital teaching competence. Unfortunately, pre-service teacher training tends to assign minimal importance to technology ethics. However, neglecting the ethical dimension of technology in education could significantly harm democratic society (Gracia Calandín, 2018). Given the advancement of technologies, including artificial intelligence, while there are positive impacts on education, such as more precise teaching by educators and personalized learning for students, there are also many negative aspects, such as privacy leakage and the widening digital divide. Hence, ethics is becoming increasingly important presently. The findings of this study confirmed the crucial role of technology ethics, and in the future, pre-service teacher training programs should place greater emphasis on ethical literacy education. Such efforts would help to enhance data literacy and promote the development of digital teaching competence among future educators.

Conclusion, limitation, and future research

To conclude, this study examined the factors that impact digital teaching competence among pre-service teachers and investigated the mediating role of data literacy. First of all, our findings indicated that technology attitudes, technology ethics, and data literacy significantly affected the pre-service teacher's digital teaching competence. Secondly, the results demonstrated that data literacy mediated between technology attitudes, technology operations, technology ethics, and digital teaching competence. Thirdly, our findings indicated that technology ethics mediated between technology attitudes and data literacy, as well as between technology attitudes and digital teaching competence. This study offered a more extensive and comprehensive understanding of the factors that may impact pre-service teachers' digital teaching competence. Findings are anticipated to benefit policymakers, researchers, and teacher educators in their efforts to merge data literacy and technology ethics to promote pre-service teachers' digital teaching competence.

Although this study has notable strengths, it also has a few limitations. Firstly, the participants included only students from a single regular university, and the gender distribution was imbalanced. As a result, the conclusions may need to be more generalizable to other universities or student populations. Secondly, the study relied solely on questionnaire data. Future research could incorporate various research methods, such as interviews and diverse samples, to validate the research findings through triangulation.

For further research, cross-national data could be compared to develop more generalized insights into pre-service teachers' digital teaching competence. In addition, comparing the differences in digital teaching competence between pre-service and in-service teachers could promote effective training programs. Lastly, an approach such as Qualitative Comparative Analysis could be applied to identify the combined factors influencing digital teaching competence.

Data availability

All data generated or analyzed during this study are included in this published article and its supplementary file.

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Author contributions

The authors confirm their contribution to the paper as follows: study conception and design: JY, JC, LL; data collection: JY, JC, LL; analysis and interpretation of results: JC, RL, LY; original draft preparation: JC, JY, ZQ, RC; language service: JC, ZQ. All authors reviewed the results and approved the final version of the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

The author sought and gained ethical approval from the Research Ethics Committee of the Jing Hengyi School of Education at Hangzhou Normal University (No. 2022028) on June 20, 2022. All procedures in this study were in accordance with the institutional research and the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all the participants.

Additional information

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Correspondence and requests for materials should be addressed to Ligao Lou or Junfeng Yang.