

Article

Constructing a Digital Competence Evaluation Framework for In-Service Teachers' Online Teaching

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Abstract: The focus on online teaching and teachers' digital competence (DC) has reached a new level following the emergence of COVID-19 and its dramatic influence on the educational industry, requiring teachers to be equipped with DC. However, there is no consensus on the measuring framework of teachers' DC. Therefore, this study aimed to construct a reliable self-evaluation framework for in-service teachers' DC during online teaching. The data of 1342 teachers with online teaching experience were obtained. The methods of data analysis included exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and item analysis. Results demonstrated that the constructed evaluation framework performed consistently with the collected data. CFA also confirmed a good model fitting of the relevant 10 factors of the teachers' DC framework. Therefore, in the teachers' DC evaluation framework, the constructs interacting with each other consist of technical knowledge (TK, four items), learner knowledge (LK, three items), pedagogical knowledge (PK, three items), ethical knowledge (EK, three items), learner technical knowledge (LTK, four items), learner pedagogical knowledge (LPK, four items), learner ethical knowledge (LEK, four items), technical pedagogical knowledge (TPK, three items), technical ethical knowledge (TEK, four items), and pedagogical ethical knowledge (PEK, three items), but in total the scale comprises 35 items. It can be an effective instrument to support in-service teachers' DC measurement for their online teaching.

Keywords: teachers' digital competence; evaluation framework; online teaching; in-service teachers



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1. Introduction

Education in many countries is currently developing in a digital direction. It is now common for teachers and students to teach and learn in a variety of online environments [1]. Online teaching has been used at almost all levels of education [2]. In addition, the focus on online teaching and teachers' digital competence (DC) has reached a new level following the emergence of the COVID-19 pandemic and its dramatic influence on the educational industry. Teaching activities around the world have been completely disrupted by the epidemic, and the teaching environment has been changed. Digital teaching management systems, digital collaboration platforms, social networks, and even telephones have become important tools for teachers to reorganize their teaching [3]. During online teaching, teachers need to use these information and communication tools effectively to ensure the smooth running of the teaching process, as well as to ensure that the relevance of the students' knowledge and skills are assessed [4,5]. Therefore, teachers' digital skills play an important role in responding to the COVID-19 crisis, but it is also necessarily an important aspect of online teaching quality and teachers' skill evaluation [6]. Teachers' DC is a prerequisite for good online teaching [7]. Teachers' DC is improved by the effective integration of technology into teaching in different learning environments, such as blended or fully online teaching environments [8,9]. Hjelsvold et al. [10] reported that some teachers regretted their lack of teaching competence when faced with online teaching, again highlighting the importance of teachers' DC. The application of digital technologies, the digitization of

teaching surroundings, and the growing popularity of online teaching all call for teachers to be competent in teaching online [11]. Therefore, it is necessary to construct an appropriate evaluation framework for teachers to effectively validate their DC and allow them to explore various elements of instruction and more easily adjust their online teaching.

However, there is currently no unified conceptual framework or measuring tool for teachers' DC. There is also little consensus among researchers on what should be measured and how such a measurement should be conducted [12]. Several frameworks have gained attention in recent years. One example is the European Framework of Educators' Digital Competence (DigCompEdu) presented by the European Commission [13], but this tool primarily considers school leadership and schools as organizations, and does not take into account individual teachers [14]. In contrast, the TPACK framework [15] is more focused on the individual teacher and acknowledges the complexity of optimizing the contribution of digital technology in the classroom, but its original form has limited use in building a more broad-based concept of teachers' DC [16]. Since the publication of TPACK, the educational landscape has changed significantly, mainly due to new digital technological innovations. Taking these changes into account, Fallon [16] argued that teachers' DC should go beyond simple digital–technical contact to include considerations such as online presence, ethics, and collaborating in and building knowledge in online environments. Further, some researchers also believe that teachers' DC cannot be narrowly focused on context-free, isolated technologies [17–19]. Scholars are calling for the expansion of the research focus on teachers' DC to include individual and sociocultural factors [16,18,20–22]. Therefore, this study aimed to construct a more comprehensive teachers' DC framework that considers these factors, to ensure that teachers understand and are equipped with this knowledge and these competencies, and that they are constantly updated and enhanced through professional learning throughout their careers.

Therefore, in order to make up for the shortcomings of the current research, this study aimed to construct a self-evaluation framework to assess in-service teachers' DC when integrating digital technologies into practical online teaching. It is hoped that the development of the conceptual framework will contribute to the conceptualization and structuring of theories and will transform teachers' teaching practices.

The structure of this article is as follows. Section 2 presents the literature review about teachers' DC. This section not only aims to position the work of this study based on the published literature, but also to identify the distance between the existing framework and teachers' DC evaluation. Section 3 introduces the methodology adopted in this study. Firstly, the research design is presented, including the preliminary design of the framework and the pretest. Then, the method and the process of data collection are described. Finally, the effectiveness measurement method of the proposed framework is explained. Section 4 presents the main measurement results. Sections 5 and 6 discuss the results of this study in detail and summarize the contributions and limitations of this study.

2. Literature Review

2.1. Teachers' Digital Competence

Digital competence (DC) is considered to be the integration of knowledge, skills, abilities, attitudes, strategies, and awareness, which helps people perform tasks using digital media and Information and Communication Technology (ICT) [17]. The education system is seen as an important player in improving DC [23]. In particular, teachers' DC has received attention. However, there is currently no unified or specific definition of teachers' DC. Teachers' DC is a complex concept that encompasses all aspects of pedagogy, society, culture, and ethics [24,25]. Teachers' DC is different from that of other individuals, and the teachers' focus is on how to effectively apply digital technology to various educational environments [21,26], such as the currently especially popular online teaching. Compared with traditional teaching, online teaching obviously has a greater requirement for teachers' DC [27]. Li et al. [28] proposed that teachers' DC is positively correlated with their online teaching behavior. Referring to From's study [11], teachers' DC in this study was defined as

the way in which teachers are able to appropriately apply digital technologies and digital environments (online teaching). In particular, digital technologies refer to the variety of digital devices and software that teachers use in online teaching, such as computers, mobile phones, and social media applications.

Additionally, teachers with DC are usually considered to merely have the technical skills for selecting appropriate digital tools for the teaching environment, and for applying them in particular teaching units [29]. However, this view has been criticized for its narrow skill focus and its failure to consider the different socio-cultural contexts in which digital technologies are used [17,30]. For example, in the use of digital technology, there tends to be a lack of consideration of ethical factors, of students' characteristics, and of other aspects, with digital technology only being used in teaching as a simple tool. Teachers' DC does not mean the same as actual or frequent use of digital technologies while teaching [19]. Other researchers have pointed out the limitations of an overly technical perspective, which ignores broader considerations including the elements of ethics, digital citizenship, security, and so on [18]. Some studies have suggested abandoning the current emphasis on skills-focused DC, and instead call for broader DC frameworks that recognize the greater diversity of knowledge and competencies required by teachers [16,19,20]. Calvani et al. [31] highlighted that DC should be the interplay between three dimensions: the technical, ethical, and cognitive dimensions. Yong et al. [32] also insisted that in order to succeed with implementing technology into the classroom, three areas of knowledge should be included in teachers' DC: technical proficiency, pedagogical competence, and social awareness. Thus, DC not only emphasizes technical skills, but it is also sensitive to socio-cultural issues such as ethics to effectively adapt to the digital environment [21]. Therefore, it is quite a challenge for teachers, who not only need to apply digital technology more effectively to their teaching, but also have to consider more broadly the use of digital technology and its impact. Furthermore, Janssen et al. [19] argued that the concept of competence needs to be constantly revised to reflect changes in technology systems and usage, and to consider the evolving nature of technology. Therefore, this study aimed to reconstruct a framework for evaluating teachers' digital competence in response to the rapidly changing educational environment.

2.2. Evaluating Teachers' Digital Competence

As there is no unified definition of teachers' DC, some frameworks or models developed by describing competence dimensions have been used to measure teachers' DC [15,33–35]. For example, the framework of DigCompEdu proposed and further implemented six competence areas required by educators [36], namely (1) professional involvement, (2) digital resources, (3) teaching and learning, (4) evaluation, (5) empowering students, and (6) promoting students' DC. However, this tool does not focus on individual teachers, but primarily considers school leadership and schools as organizations [1]. The most representative framework of teachers' DC is the technological pedagogical content knowledge (TPACK) proposed by Koehler et al. [37]. The TPACK framework stems from Shulman's PCK [38]. Specifically, TPCK as an extension of the PCK, and TP(A)CK is derived from the interaction and intersection between these dimensions [39]. The TPACK framework has been used in some studies as the basis for measuring teachers' DC [40–45]. However, the TPACK framework has been criticized for not taking teachers' cognitive beliefs and values about teaching and learning into account [46]. Moreover, TPACK ignores other teaching factors, such as the learners' knowledge of the teaching content [46–48]. A survey instrument for measuring TPACK tailored for teachers' online teaching was developed [49]. However, the findings showed a strong correlation between pedagogical knowledge and content knowledge, which calls into question the distinctiveness between these domains as they are difficult to distinguish. Archambault and Barnett suggested that this results in less predictive or inefficient development of new knowledge [50]. Therefore, based on previous experience, content knowledge was not included in the development of the framework for evaluating teachers' DC for online teaching in this study. In addition, some improved

versions of TPACK still have deficiencies. For example, the ICT-TPACK proposed by Angeli and Valanides [46] does not account for the interconnections between constructs [51], and it is difficult to measure clearly and easily [52]. In addition, several self-assessment instruments on DC for teachers have been developed [53–55], but they mainly focus on pre-service teachers.

Therefore, in order to make up for the shortcomings of the above research, this study further investigated the structure of teachers' DC in online teaching with the aim of reconstructing the evaluation framework of in-service teachers' DC in online teaching.

2.3. Research Purpose

Teachers' DC is an important factor in the success of online teaching. According to the research on teachers' DC measurement, it can be improved in two main ways.

Firstly, the attention to the knowledge of learners and their characteristics is insufficient. The knowledge of learner characteristics is considered to be the basis of teaching [15]. Shulman [56] proposed seven basic aspects of teachers' competence, one of which was the knowledge of learners and their characteristics, but it was weakened in the process of developing TPACK. Teachers should consider the characteristics and needs of the student population when designing activities using digital technologies [57–59], for example, students' readiness for online learning and perceived challenges [60], and learners' cognitive load in online learning [61]. Online teaching requires teachers to have the ability and knowledge to support students [45]. Li et al. [28] believed that the perception of the learners' characteristics can be regarded as an important contextual variable affecting teachers' DC in online teaching. Importantly, being a teacher with DC means being able to help students develop their DC according to their characteristics [26,36]. However, the learners' knowledge is not taken into account sufficiently in the teachers' competence framework.

In addition, the measurement of ethical knowledge has been neglected. It is essential that teachers' DC includes familiarity with ethical issues. Ethics are mentioned in many definitions of DC [19,21,31]; however, it is only a concept and lacks measurement practice. Asamoah [62] believed that ethical knowledge should be an important supplement to teachers' TPACK, so that teachers can carry out hybrid or all-online teaching more effectively. The digital technology usage, pedagogical design, and guidance of students should follow ethical practices in online teaching. Furthermore, teachers should know what is ethically correct, and should try to avoid wrong perceptions or behaviors.

Therefore, this study constructed a model for evaluating in-service teachers' DC for online teaching (see Figure 1). The proposed evaluation framework incorporates the interplay and intersection of four types of basic knowledge: learner knowledge (LK), technical knowledge (TK), pedagogical knowledge (PK), and ethical knowledge (EK). However, it goes beyond these four knowledge bases. The teachers' DC framework further emphasizes the types of knowledge that are located at six key intersections: learner technical knowledge (LTK), learner pedagogical knowledge (LPK), learner ethical knowledge (LEK), technical pedagogical knowledge (TPK), technical ethical knowledge (TEK), and pedagogical ethical knowledge (PEK). Therefore, this study aimed to construct and test whether the 10-dimensional evaluation framework is an effective instrument for measuring teachers' DC.

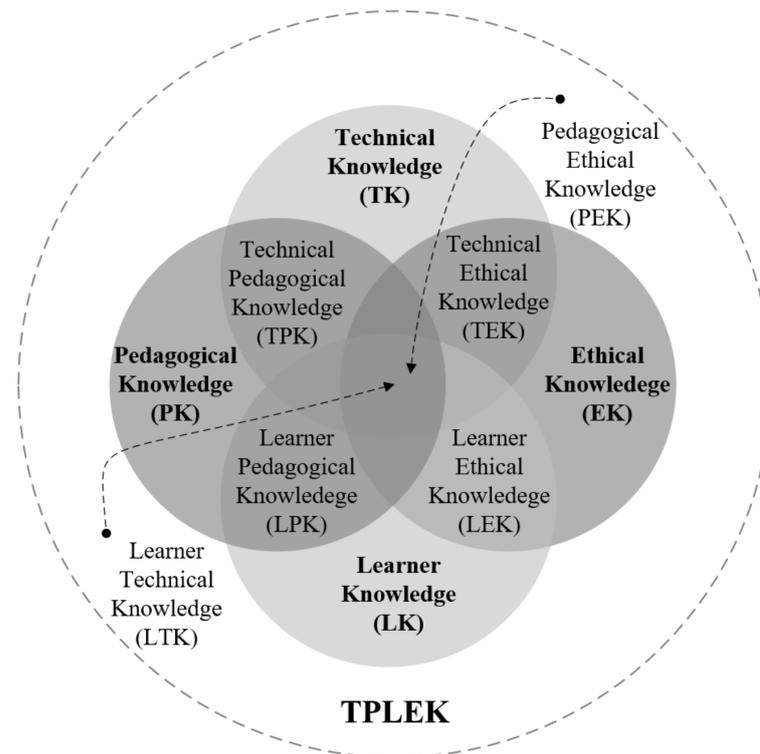


Figure 1. A model for evaluating teachers' DC for online teaching.

3. Methods

3.1. Research Design

3.1.1. Preliminary Development of the Framework for Evaluating Teachers' Digital Competence

To address the gap in the existing research, a teachers' digital competence evaluation framework for online teaching was developed in this study, including the following 10 dimensions: LK (5 items), TK (4 items), PK (7 items), EK (4 items), LTK (4 items), LPK (4 items), LEK (4 items), TPK (4 items), TEK (4 items), and PEK (4 items). As shown in Table 1, a total of 44 items were measured using a 5-point Likert-style questionnaire (5 = *strongly agree*, 4 = *agree*, 3 = *neutral*, 2 = *disagree*, 1 = *strongly disagree*).

3.1.2. Pretest and Formal Test

Three educational technology experts and two university professors were invited to examine the effectiveness of the 44 items. To enhance the objectivity and accuracy of the questionnaire, 20 volunteers filled in the questionnaire one by one. Then, the expression and presentation of the questionnaire were improved based on their feedback. Finally, six questions about personal background information (including gender, teaching duration, education background, teaching subjects, class, and school) were added to the scale (see Table 1) to construct a 50-item questionnaire.

Table 1. Dimensions and items of the teachers' DC evaluation framework.

Dimension	No.	Indicator	Code	Source
Learner Knowledge (LK)	1	I know the general trajectory of students' physical and mental development	LK1	Self-compiled based on the general law of student development
	2	I know the age characteristics of student development	LK2	
	3	I know the common problems of students associated with their physical and mental development	LK3	
	4	I can effectively solve the common problems of students related to their physical and mental development	LK4	
	5	I know the knowledge level of students at different stages	LK5	
Technological Knowledge (TK)	6	I have the ability to solve hardware-related technical problems	TK1	Ekrem and Recep [63]
	7	I can deal with various problems related to software	TK2	
	8	I have the ability to help students solve computer technology problems	TK3	
	9	I have the ability to solve some unexpected situations in multimedia teaching, such as network connection interruption	TK4	
Pedagogical Knowledge (PK)	10	I have the ability to plan the order of topics to be taught in the course	PK1	Ekrem and Recep [63]
	11	I have the ability to determine the scope of knowledge to be taught in the course	PK2	
	12	I have the ability to prepare appropriate teaching materials according to the curriculum standards of the subject	PK3	
	13	I have the ability to relate knowledge points in this course to other subjects	PK4	
	14	I can use various teaching strategies to connect different knowledge points with the actual life of students	PK5	
	15	I can adjust teaching methods based on student performance or learning feedback	PK6	
	16	I can quickly adjust teaching methods or strategies to maintain class order in case of teaching emergencies	PK7	
Ethical Knowledge (EK)	17	I know and abide by the professional code of ethics for teachers	EK1	Self-compiled based on teacher professional ethics requirements
	18	I know and abide by education laws and regulations	EK2	
	19	I love education	EK3	
	20	I bravely fight resolutely against all acts endangering the cause of education	EK4	
Learner Technological Knowledge (LTK)	21	I can use appropriate teaching tools according to the age characteristics of students	LTK1	Self-compiled based on learner knowledge and teacher's technological knowledge
	22	I can use modern intelligent auxiliary tools to understand students' development status, such as changes in grades	LTK2	
	23	I can use technology to communicate well with students about their learning and psychology	LTK3	
	24	I can use technology to promote students' learning progress and physical and mental development	LTK4	
Learner Pedagogical Knowledge (LPK)	25	I can teach based on students' existing knowledge level	LPK1	Self-compiled based on learner knowledge and teacher's pedagogical knowledge
	26	I can teach based on students' individual differences	LPK2	
	27	I can teach in accordance with the general traits of students' physical and mental development at the present stage	LPK3	
	28	I can use appropriate teaching methods according to the characteristics of students	LPK4	
Learner Ethical Knowledge (LEK)	29	I fulfill teachers' professional responsibilities conscientiously and be responsible to students, parents, and society	LEK1	Self-compiled based on learner knowledge and teacher's ethical knowledge
	30	I care for students	LEK2	
	31	I care for students' physical and mental health changes and development during daily campus life	LEK3	
	32	I sometimes use corporal punishment to punish disobedient students	LEK4	
Technological Pedagogical Knowledge (TPK)	33	I have the ability to encourage students to communicate with each other	TPK1	Ekrem and Recep [63]
	34	I can use different teaching methods in the classroom	TPK2	
	35	I have the ability to create a learning environment that enables students to quickly master new knowledge and skills	TPK3	
	36	I prefer to use intelligent teaching auxiliary tools	TPK4	
Technological Ethical Knowledge (TEK)	37	I protect students' privacy while using technology to understand students	TEK1	Self-compiled based on the notion of technology ethical
	38	I can treat technology rationally and do not over-rely on it or abuse it	TEK2	
	39	I consider the emotional value of students while using technology. For example, the technical results show that students' performance is average, but their attitude is getting better and better	TEK3	
	40	I consider students' subjective feelings about the technology while using technology, such as acceptance	TEK4	
Pedagogical Ethical Knowledge (PEK)	41	I consider the physical and mental health of students when using teaching methods	PEK1	Self-compiled based on the relevant content of educational purpose
	42	I pay attention to students' personal development in teaching (take education as the purpose)	PEK2	
	43	Improving grades is the most important purpose of my teaching	PEK3	
	44	I pay attention to screening the teaching content that is harmful to students' physical and mental health	PEK4	

3.2. Data Collection

In October 2021, questionnaires were distributed to teachers in 25 schools in the east of China via an online platform called *Questionnaire Star*. The teachers, who come from local primary and secondary schools, often have to resort to online teaching because of

the COVID-19 pandemic. Thus, these in-service teachers with online teaching experience were randomly selected to fill out the questionnaire. This survey aimed to explore teachers' perceptions of their own DC. Respondents were required to answer all 50 items on the questionnaire before they could submit it. A statement about the absence of commercial or other uses of the information was provided in the first part of the questionnaire. Respondents were assured that their information was confidential and that they were allowed to withdraw from the process at any time if they wanted to. Moreover, the purpose, duration, and anonymity of the survey were explained specifically to ensure the validity and authenticity of the respondents' answers. All participants agreed to participate in the study. A total of 1450 questionnaires were collected. Then, questionnaires submitted within 120 s, or all with the same answers, were deemed invalid. Finally, 108 invalid questionnaires were eliminated, and the remaining 1342 valid questionnaires were used in this study.

3.3. Measurement Tools

To construct an evaluation framework of teachers' DC and to confirm its validity, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and item analysis were carried out. Firstly, the 1342 samples were randomly assigned to two groups, with 671 samples in each. EFA was used to analyze the first group of samples. After EFA was performed, as Vogel et al. [64] suggested, the framework was refined by utilizing the method of principal component analysis (PCA). CFA was then used to confirm the results using the second group of 671 samples. Lastly, all samples were analyzed to test the differentiation and suitability of the items. SPSS 22.0 and AMOS 24.0 were applied to analyze the collected data.

4. Results

4.1. Exploratory Factor Analysis

SPSS 22.0 was used for conducting EFA, and the maximum variance method was adopted for factor rotation. The KMO value of the questionnaire was 0.97, and a strong relevance between variables was demonstrated by the Bartlett sphericity test ($\chi^2 = 94,819.322$; $p = 0.000 < 0.001$), showing the appropriateness of EFA [65].

The PCA method was adopted to examine the validity of the measured framework dimensions by extracting factors, and finally 10 factors were obtained. The preliminary analysis found a correlation between the factors, but the oblique rotation analysis method was more convincing. However, Kieffer [66] suggested that two strategies should be used for exploratory factor analysis to achieve a repeatable analysis. In general, if the analysis results of orthogonal rotation and oblique rotation show no significant difference, the results obtained by the orthogonal rotation method can be applied directly. Thus, two methods were adopted for EFA, including optimal skew and maximum variance orthogonal rotation. Then, the analysis results of the two methods were generally parallel. The interpretability of the factors was determined by the maximum variance rotation method. Table 2 presents the result of the component transformation matrix. According to Fabrigar et al. [67], the normalized factor loading of all the factors (more than 0.5) in Table 3 demonstrated that these items showed good explainability.

Table 2. The factor analysis of Teachers' DC framework ($N = 671$).

Items	1	2	3	4	5	6	7	8	9	10
LK1		0.806								
LK2		0.810								
LK3		0.820								
LK4		0.798								
LK5		0.791								
TK1			0.842							
TK2			0.887							
TK3			0.886							
TK4			0.807							
PK1	0.695									
PK2	0.699									
PK3	0.715									
PK4	0.718									
PK5	0.663									
PK6	0.663									
PK7	0.637									
EK1					0.803					
EK2					0.803					
EK3					0.782					
EK4					0.742					
LTK1						0.777				
LTK2						0.799				
LTK3						0.815				
LTK4						0.817				
LPK1								0.777		
LPK2								0.778		
LPK3								0.780		
LPK4								0.779		
LEK1							0.819			
LEK2							0.826			
LEK3							0.819			
LEK4							0.764			
TPK1									0.796	
TPK2									0.814	
TPK3									0.805	
TPK4									0.715	
TEK1				0.789						
TEK2				0.813						
TEK3				0.810						
TEK4				0.798						
PEK1										0.746
PEK2										0.753
PEK3										0.691
PEK4										0.749

4.2. Confirmatory Factor Analysis

The validity, convergence, and distinctiveness of the evaluation model were determined by first-order CFA. CFA was applied to investigate the relationships between each factor, and then we constructed the evaluation framework of teachers' DC.

4.2.1. Fitting Validity Analysis for the Framework

As shown in Figure 2, first-order CFA was conducted. According to Hair et al. [68], items that do not meet the standard load (less than 0.5) must be eliminated. The absolute and relative fitting indexes were applied to verify the framework fit. The chi-square/ df in this research was 3.651, and the value of RMSEA showed 0.044 (<0.08) [69]. In addition, the goodness-of-fit index (GFI) and adjusted fitness index (AGFI) showed 0.923 and 0.906,

respectively, which met the reference standard proposed by Foster et al. [70]. Moreover, according to Hair et al. [66], the normed fitness index (NFI), comparative fitness index (CFI), incremental fitness index (IFI), and relative fitness index (RFI) showed 0.975, 0.982, and 0.972 (>0.9). In addition, the values of simplifying the parsimonious normed fit index (PNFI), and parsimonious goodness-of-fit index (PGFI) were more than 0.5. Therefore, these results indicated the good fitting validity of the framework (see Table 4).

Table 3. The eigenvalues and contribution rates of the 10-dimension framework.

Dimension	Eigenvalue	Percentage of Variance	Cumulative Variance Contribution Rate
1	24.041	54.639%	54.639%
2	3.240	7.363%	62.002%
3	2.417	5.494%	67.495%
4	1.933	4.393%	71.889%
5	1.658	3.769%	75.657%
6	1.378	3.131%	78.789%
7	1.346	3.059%	81.848%
8	1.257	2.856%	84.704%
9	1.163	2.643%	87.347%
10	1.021	2.320%	89.667%

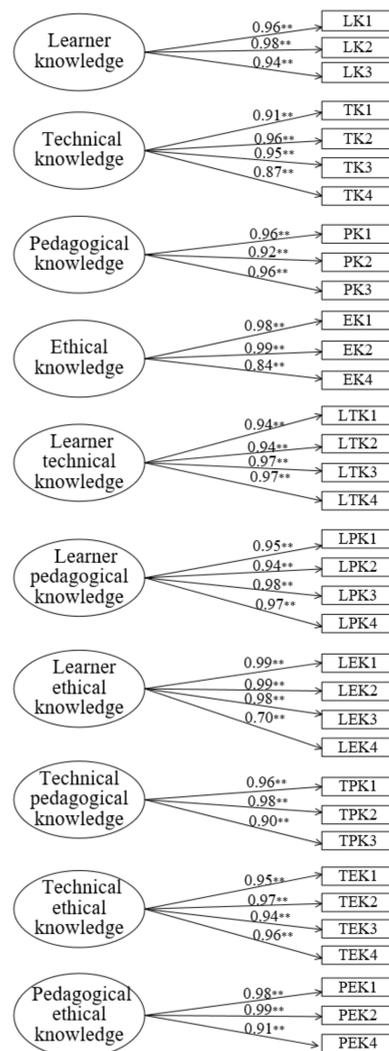


Figure 2. The first-order CFA model. ** $p < 0.01$.

Table 4. The fitting index of the evaluation framework.

Type	Fitting Index	Threshold	Values	Results
Absolute fit index	Chi-square/ <i>df</i>	<5	3.651	Acceptable
	RMSEA	<0.08	0.044	Acceptable
	GFI	>0.8	0.923	Acceptable
	AGFI	>0.8	0.906	Acceptable
	NFI	>0.9	0.975	Acceptable
Relative fit index	CFI	>0.9	0.982	Acceptable
Incremental fit index	IFI	>0.9	0.982	Acceptable
	RFI	>0.9	0.972	Acceptable
Streamlining fit index	PNFI	>0.5	0.844	Acceptable
Parsimonious fit index	PGFI	>0.5	0.755	Acceptable

Lastly, LK4, LK5, PK4, PK5, PK6, PK7, EK3, TPK4, and PEK3 were eliminated as they did not meet the criteria. The remaining 35 items were accepted and underwent further analysis, specifically: LK (three items), TK (four items), PK (three items), EK (three items), LTK (four items), LPK (four items), LEK (four items), TPK (three items), TEK (four items), and PEK (three items).

4.2.2. Convergence Validity Analysis for the Framework

The results of the CFA are shown in Table 5. The comprehensive reliability (CR) and average variance extracted (AVE) were used to test the construct validity of the framework. According to Hair et al. [66], the CR value of all items should be more than 0.7. Thus, the CR of the 35 remaining items is considered to be good. What is more, Fornell and Larcker [71] pointed out that if the AVE is higher than 0.5, the framework shows good convergence validity. Therefore, the results in Table 5 show that this evaluation framework has high validity and is reasonable.

4.2.3. Reliability Analysis of the Scale

The Cronbach's alpha value [72] and composite reliability were applied to evaluate the reliability of the scale items, which has been used in similar studies [73,74]. Due to the exclusion of LK4, LK5, PK4, PK5, PK6, PK7, EK3, TPK4, and PEK3 by exploratory factor analysis and confirmatory factor analysis, the scale was adjusted. Therefore, the results showed that the adjusted scale had good reliability ($\alpha = 0.974$). Specifically, the Cronbach's alpha values of the 10 factors were 0.973 (LK), 0.956 (TK), 0.961 (PK), 0.953 (EK), 0.976 (LTK), 0.979 (LPK), 0.946 (LEK), 0.961 (TPK), 0.976 (TEK), and 0.971 (PEK). As shown in Table 5, the composite reliabilities of the 10 factors were 0.9735 (LK), 0.9571 (TK), 0.9612 (PK), 0.9580 (EK), 0.9761 (LTK), 0.9794 (LPK), 0.9567 (LEK), 0.8955 (TPK), 0.9763 (TEK), and 0.9195 (PEK), indicating their good reliability [75].

4.2.4. Discriminant Validity Analysis for the Framework

Discriminant validity of the framework could be ensured by testing the correlation matrix among dimensions [76]. Schumacker and Lomax [77] proposed that in the structural discriminant validity analysis of tools, the AVE square root of all the factors must be more than the absolute value of the Pearson correlation coefficient between two factors in order to be recognized as having discriminant validity. Therefore, as shown in Table 6, the results of the structural discriminant validity analysis indicated that this framework had good discriminant validity.

Table 5. Results of the confirmatory factor analysis.

Potential Variable	Item	Normalized Factor Loading	CR	AVE
Learner Knowledge (LK)	LK1	0.959	0.9735	0.9244
	LK2	0.981		
	LK3	0.944		
Technology Knowledge (TK)	TK1	0.911	0.9571	0.8481
	TK2	0.958		
	TK3	0.946		
	TK4	0.866		
Pedagogy Knowledge (PK)	PK1	0.957	0.9612	0.8921
	PK2	0.920		
	PK3	0.956		
Ethical Knowledge (EK)	EK1	0.984	0.9580	0.8844
	EK2	0.993		
	EK4	0.836		
Learner Technological Knowledge (LTK)	LTK1	0.939	0.9761	0.9108
	LTK2	0.938		
	LTK3	0.969		
	LTK4	0.971		
LearnerPedagogical Knowledge (LPK)	LPK1	0.951	0.9794	0.9223
	LPK2	0.943		
	LPK3	0.976		
	LPK4	0.971		
Learner Ethical Knowledge (LEK)	LEK1	0.986	0.9567	0.8489
	LEK2	0.988		
	LEK3	0.977		
	LEK4	0.702		
Technological Pedagogical Knowledge (TPK)	TPK1	0.956	0.8955	0.9625
	TPK2	0.982		
	TPK3	0.899		
Technological Ethical Knowledge (TEK)	TEK1	0.947	0.9763	0.9116
	TEK2	0.969		
	TEK3	0.945		
	TEK4	0.958		
Pedagogical Ethical Knowledge (PEK)	PEK1	0.978	0.9195	0.9716
	PEK2	0.986		
	PEK4	0.911		

Table 6. The results of interrelated coefficient matrix and square roots of AVE.

Construct	LK	TK	PK	EK	LTK	LPK	LEK	TPK	TEK	PEK
LK	0.961									
TK	0.479 **	0.921								
PK	0.668 **	0.524 **	0.945							
EK	0.643 **	0.379 **	0.689 **	0.940						
LTK	0.542 **	0.543 **	0.620 **	0.468 **	0.954					
LPK	0.572 **	0.480 **	0.673 **	0.512 **	0.686 **	0.960				
LEK	0.478 **	0.350 **	0.566 **	0.595 **	0.422 **	0.478 **	0.921			
TPK	0.466 **	0.336 **	0.558 **	0.503 **	0.510 **	0.546 **	0.573 **	0.981		
TEK	0.533 **	0.423 **	0.654 **	0.581 **	0.547 **	0.578 **	0.565 **	0.559 **	0.955	
PEK	0.523 **	0.370 **	0.625 **	0.595 **	0.525 **	0.583 **	0.598 **	0.568 **	0.646 **	0.986

Note: The square root of AVE is located on the diagonal, and the remaining values are the Pearson correlation coefficient. ** $p < 0.01$.

In conclusion, the first-order CFA demonstrated that this evaluation framework shows good convergence validity and discriminant validity; it is thus sound to claim that it has good construct validity. Therefore, this evaluation framework is suitable for data analysis.

4.3. Item Analysis

For verifying the suitability and distinctiveness of the constructed items, item analysis was used in this study. Two important parts were examined in the item analysis, namely decisive values and the interrelated coefficient between items and the gross score for each dimension. Therefore, the method of the independent samples *t* test was applied to further analyze low-group versus high-group items. According to Aridag and Yüksel's recommendation [78], the bottom 27% and top 27% of the 1342 samples were identified as the low and high groups, respectively. Further, items with dimensional Pearson correlation coefficients and standardized factor loadings that did not reach the standard value (less than 0.4 and 0.45, respectively) were eliminated [79]. Finally, for the remaining 35 items, the decisive values were higher than 0.3, and the gross interrelated coefficient between questions and items was higher than 0.4. Overall, the item analysis results showed that the remaining 35 items reached the standard.

5. Discussion

Teachers' DC is a prerequisite for good online teaching [7]. This study addresses two important questions regarding what kind of DC in-service teachers need to be equipped with and how to measure it in the age of online teaching. Therefore, the construction of the teachers' DC evaluation framework offers teachers help to support their online teaching quality evaluation, but also to improve teachers' teaching practices through evaluation. Practical and useful advice was provided to teachers in terms of TK, PK, LK, EK, LTK, LPK, LEK, TPK, TEK, and PEK. For example, learner technological knowledge indicates that teachers should use technology to communicate well with students about their learning and psychology, and to promote students' learning progress and physical and mental development. Furthermore, according to technological ethical knowledge, teachers should consider students' emotional value and their subjective feelings about the technology while using it, such as acceptance. Teachers are also reminded to treat technology rationally and to not over-rely on it or abuse it.

The teachers' DC evaluation framework constructed in this study differs from previous evaluation frameworks such as TPACK. In addition to teachers' technical and pedagogical knowledge and competences, which are often considered, the framework in this study focuses more on socio-cultural factors to prevent the narrowness of digital technology in teachers' DC. Specifically, the knowledge of ethics and student development was introduced into the teachers' DC. Among them, teachers' ethical knowledge is very important in online teaching practice. Teachers should be equipped to operate ethically in an increasingly digital teaching environment. The importance of teachers' ethical knowledge has also been highlighted in several previous studies about teachers' DC [16,20,62]. In addition, this study also emphasizes that learners' knowledge should be included in teachers' DC. Learner knowledge refers to the competence of teachers to provide adaptive learning experience for learners by adjusting teaching methods according to their different characteristics and needs. Hsu [80] and Nielsen and Kreiner [81] have discussed in prior studies the necessity for teachers to be equipped with the knowledge of learners and their learning effectiveness. In fact, the use of digital technology makes learning more accessible and promotes personalized educational content tailored to students [36]. Especially in online teaching, which is often a long-distance interaction between instructors and learners, there is more focus on how teachers cross the boundaries of time and space to provide quality teaching for students. Therefore, teachers should be equipped with knowledge about learner development. However, content knowledge, as one of the elements of TPACK, was not included in the framework of this study. Rubio et al. [44] pointed out that greater self-knowledge of pedagogical or technological content is more conducive to developing teachers' DC than knowledge of subject content. According to the research of Archambault and Crippen [49], content knowledge and pedagogical knowledge in online teaching have a strong correlation, resulting in a lack of domain distinctiveness and difficulty distinguishing them, especially when it comes to content knowledge and pedagogical content knowledge.

Although Schulman [38] makes a theoretical distinction between these two concepts, the results of experimental studies are often quite contradictory [82,83]. Therefore, in order to ensure that each domain of the framework has good distinctiveness and can better measure knowledge and abilities, content knowledge was not included in the framework of this study. In conclusion, the framework of teachers' DC evaluation constructed in this study is a clear addition to and modification of the previous knowledge field.

6. Conclusions

This study further investigated the potential factors of teachers' DC to construct a framework for evaluating in-service teachers' DC for online teaching, and to test its effectiveness. The EFA, CFA, and item analysis methods were used in this study to construct a 10-factor teachers' DC evaluation framework. The results indicate that the 10-factor framework constructed in this study has good reliability and validity.

6.1. Implications

Major implications of this study are twofold. On the one hand, a 10-factor evaluation framework was constructed in this study for in-service teachers' DC in online teaching. Socio-cultural factors are emphasized in this framework; therefore, it provides a broader and richer technological framework. Importantly, this framework can be applied as a useful instrument to support teachers' DC evaluation, and to offer teachers a reference to further adjust and enhance their online teaching practice. Specifically, these framework indicators clearly show the various types of knowledge and abilities that teachers should master in the era of online teaching. In the teaching process, teachers have the responsibility to review their own teaching practices at any time, and to use appropriate measures to reinforce the knowledge they lack and to enhance their professional abilities. In this way, teachers improve their teaching efficiency and provide a better teaching experience to students. On the other hand, the development of this conceptual framework also contributes to the conceptualization and structuring of theories of teachers' DC. It not only develops the concept of teachers' DC, but also adds a new perspective to explore the structural elements of teachers' DC and provides support for the sustainable development of teacher digital competence.

6.2. Limitations and Future Work

There are two main limitations of this study. First, this research aimed to provide teachers with pertinent information about what kind of DC they would like to have to improve their online teaching effectiveness. However, as the rapid development of digital technology creates more innovative forms of online learning and teaching, teachers should continue to broaden their knowledge repertoire. Future research should explore more knowledge to enable teachers to effectively and efficiently cope with the digital teaching environment. Second, this evaluation framework of teachers' DC is still in the theoretical research stage and has not yet been put into practice. Therefore, further research should apply the framework to practical teaching and improve its applicability and usability according to practical feedback.

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