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Evaluating the teaching ability of double-qualified teachers in Chinese vocational education: A questionnaire validation study

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ABSTRACT

The Chinese government actively promotes the high-quality development of modern vocational education, placing higher demands on the professionalism and practical skills of "Double-Qualified" Teachers (DQTs) in higher vocational colleges. This initiative encourages teachers to innovate their teaching methods and supports educational reform. As a result, effectively measuring and evaluating the teaching abilities of DQTs in higher vocational colleges has become a significant research focus. This study aims to develop and validate a questionnaire to assess the teaching abilities of DQTs in higher vocational colleges based on the vocational education DQTs' teaching ability evaluation index system and the TPACK framework. The study involved surveying 454 DQTs from eight higher vocational colleges in China using a questionnaire, with data analysis conducted through SPSS 27.0 and Amos 26.0 software. The results indicate that the questionnaire demonstrates high reliability and validity. Among the ten measurement models tested, the six-factor model shows the best fit. This study offers new perspectives and tools for understanding and evaluating the integration of technology into DQTs' subject matter knowledge, with important implications for the training and assessment of DQTs. It also provides insights and recommendations for higher vocational college administrators and DQTs.

1. Introduction

Double-qualified teachers (DQTs) are educators who possess both theoretical knowledge and practical teaching skills, understand advanced teaching philosophies and methods, and actively engage in teaching reform and research (MOE, 2022a). They are a crucial support for higher vocational education (MOE, 2019b). The Chinese government is strongly promoting the development of modern vocational education, which places higher demands on the professionalism and practical abilities of DQTs in higher vocational colleges. The government encourages these teachers to innovate in their teaching approaches, advance the reform and innovation of vocational education, and strengthen the system that ensures the quality of vocational education and training (MOE, 2019a; GOSC, 2021). The Opinions on Deepening the Reform of the Construction of a Modern Vocational Education System emphasize the need to deepen the structural reform of the supply side of vocational education, to establish and improve a graded vocational education and training system with multiple forms of articulation, multichannel growth, and sustainable development, and to promote the coordinated development of vocational education and popularization and the mutual integration of vocational education and training (MOE, 2022b). Therefore, how to effectively measure and evaluate the teaching ability of DQTs in higher vocational colleges has become an essential and practically significant research topic.

This study aimed to develop and validate a questionnaire on the teaching competence of DQTs in higher vocational colleges based on the Han et al. (2021) evaluation index system of the teaching competence of DQTs in vocational education and the essential competence qualities of DQTs in vocational colleges, Technological Pedagogical Content Knowledge (TPACK) framework, to develop and validate a questionnaire on the teaching ability of DQTs in higher vocational colleges and to explore its reliability, validity and factor structure. We applied

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the TPACK framework to the measurement and evaluation of the teaching competence of DQTs in higher vocational colleges to provide new perspectives and tools for understanding and evaluating the subject matter pedagogical knowledge of DQTs in integrating technology. The TPACK framework emphasizes that subject matter pedagogical knowledge for integrating technology is a complex body of knowledge consisting of three core types of knowledge and their interactions, which requires teachers to be capable of effectively integrating information technology with pedagogical content and methodology for adequate information technology-based teaching and learning activities within a specific subject area (Zhang and Wang, 2019). The study constructed ten different test models, and after confirmatory factor analysis (CFA), we concluded that the six-factor model could best reflect the multidimensionality and complexity of the teaching ability of DQTs in higher vocational colleges. In addition, we comprehensively examined the reliability and validity of the questionnaire. We found that the questionnaire has a high degree of internal consistency, reliability, and validity and can be used as an effective assessment instrument. These findings are highly important for promoting the practice of DQT training and evaluation and provide inspiration or suggestions for different audiences, such as administrators of higher vocational colleges and DQTs. This study attempts to answer the following research questions: How can a questionnaire on the teaching ability of DQTs in higher vocational colleges be developed based on an index system for evaluating the teaching ability of DQTs in vocational education and the TPACK framework? What are the reliability and validity of the questionnaire? Which test model best reflects the multidimensionality and complexity of DQTs' teaching ability in higher vocational colleges?

In this study, we used a questionnaire to collect data from 454 DQTs in eight higher vocational colleges in China and analyzed the data using SPSS 27.0 and Amos 26.0 software. Through confirmatory factor analysis, we compared the fit and explanatory power of different measurement models and selected the model that best reflected the multidimensionality and complexity of teachers' teaching ability. We also comprehensively tested the reliability and validity of the questionnaire, and the results showed that the questionnaire has high reliability and validity and can be used as a valid assessment tool. At the end of the study, we summarized the main findings and made suggestions for optimizing and improving the questionnaire.

2. Literature review

2.1. Current research on the teaching abilities of DQTs

DQTs in higher vocational colleges are an essential support force for vocational education (MOE, 2019b). To meet the development needs of national vocational education, the MOE (2022a) issued a notice on the identification of DQTs in vocational education. The appendix of the "Basic Standards for DQTs in Vocational Education" clearly states that DQTs in higher vocational colleges should have appropriate theoretical and practical teaching abilities, master advanced teaching concepts and teaching methods, and actively participate in teaching reform and research. They should be able to adopt various teaching modes and effective teaching methods. They should be able to adopt various teaching modes and effectively use modern information technology to carry out their teaching.

To effectively evaluate and improve the ability of DQTs to teach in colleges, it is necessary to measure this ability scientifically. At present, some achievements have been made in the research on the teaching ability of vocational education teachers at home and abroad. However, there are still some areas for improvement and differences. For example, the following five pieces of literature are compared and analyzed regarding the content and framework of vocational education teachers' teaching abilities.

Rofiq et al. (2019) concluded that the standard competencies of professional teacher candidates could be generally categorized into five domains: essential competencies, competencies in the professional field, managerial competencies, personal competencies, and social competencies. They used Delphi and hierarchical analysis to collect opinions from experts and stakeholders about the knowledge, skills, and attitudes that professional teacher candidates should possess. They provided specific indicators and weights for each domain.

Moreover, Diep and Hartmann (2016) proposed a framework of teaching competencies for vocational education teachers that meet sustainable development goals, stating that vocational teachers should acquire the necessary competencies for continued development and have the necessary knowledge. They divided these competencies into three levels—cognitive, affective, and behavioral—and provided specific content and assessment methods for each level. In a similar vein, Ismail et al. (2018) constructed a framework of teaching competencies for vocational education teachers based on a management competency perspective, a work process perspective, and a teaching activity perspective, which included three first-level dimensions: personal attributes and professionalism, teaching and learning, and training and technological innovation. They used literature analysis, questionnaires, and interviews to collect information about the qualities that Technical and Vocational Education Training (TVET) educators should possess, drawing from sources such as literature, policy documents, industry needs, and stakeholders. They provided specific indicators and assessment methods for each dimension.

Additionally, Liu et al. (2021) analyzed a questionnaire's reliability, validity, and factors for evaluating teachers' educational information competencies in higher vocational colleges. They measured teachers' teaching competencies in two dimensions: teachers' level of information teaching competencies and the external conditions of information teaching in colleges and universities. They used a questionnaire method to collect data about the knowledge, skills, and attitudes required in information teaching from teachers in higher vocational colleges. They constructed four dimensions of teachers' level of competence in information teaching (i.e., information teaching awareness, information teaching knowledge, information teaching skills, and information teaching effectiveness) and three dimensions of external conditions of information teaching in colleges (i.e., information environment, information support, and information policy). Liu et al. (2020) proposed that the professional competencies of higher education teachers include the following aspects: information knowledge skills, information teaching design, information teaching implementation, information teaching evaluation, and information teaching research.

The content and levels of teachers' competencies emphasized in these studies differed, mainly involving the following five core categories: (i) teaching technologies, pedagogies, teaching contents, and teaching environments; (ii) essential competencies, professional competencies, management competencies, and innovation competencies possessed by teachers; (iii) cognitive, affective and behavioral layers of teachers' competencies; (iv) teachers' PK, professional skills, professional values, professional attitudes and professional practices; and (v) essential information competencies, information design competencies, information implementation competencies and information evaluation competencies possessed by teachers. The research methods and data sources used varied from Delphi and hierarchical analysis to literature analysis, questionnaires, and interviews. These studies reflect the current emphasis and exploration of teachers' teaching competencies in professional teacher education, but some aspects could be improved and corrected.

All these studies reflect the current emphasis and exploration of teachers' teaching abilities in the field of vocational teacher education, but there are also some deficiencies and differences. They are mainly manifested in the following aspects: first, they do not consider the characteristics and significance of DQTs and lack pertinence and effectiveness and should construct an evaluation index system suitable for their characteristics and development; second, they do not compare and integrate different evaluation frameworks and lack theoretical support and significance of guidance and should propose a comprehensive, systematic and operative evaluation framework; third, they do not analyze the influencing factors and development path of evaluation and lack a dynamic monitoring and feedback mechanism, which should take into account teachers' personal characteristics, the teaching environment, the teaching objectives and other factors and provide effective feedback and support; fourth, they do not measure and evaluate the teachers' ability to integrate information technology and lack concern and attention to the innovation of integrating information technology and teaching, and they should reflect on the integration and innovation of the evaluation, and appropriate methods and tools should be used for measurement and evaluation. Therefore, there is a need to verify and improve the evaluation of DQTs' teaching ability in higher vocational colleges in future studies.

2.2. Theoretical basis of test models

The theoretical framework of technological pedagogical content knowledge (TPACK), proposed by Koehler and Mishra (2005), is based on disciplinary pedagogical knowledge (PCK) proposed by Shulman (Phillips et al., 2019). As shown in Fig. 1, the TPACK framework involves three core elements: pedagogical content knowledge (PCK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPK).

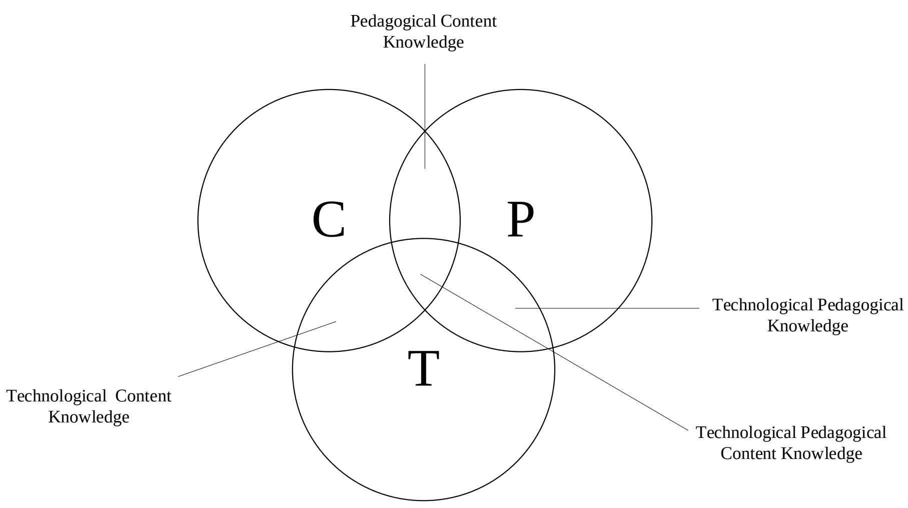

Fig. 1: The components of technological pedagogical content knowledge (Koehler and Mishra, 2005)

Subsequent academics have offered more comprehensive interpretations of the TRACK framework, building upon its theoretical growth and practical implementation. Graham (2011) defined the TPACK framework as consisting of three fundamental parts: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). Additionally, there are four composite elements within the framework: PCK, TCK, TPK, and technological pedagogical content knowledge (TPACK). The framework shown in Fig. 2 emphasizes that the disciplinary pedagogical knowledge of integrated technology is a complex body of knowledge consisting of three core knowledge areas and their interactions, requiring teachers to be able to effectively integrate information technology with pedagogical content and methods to achieve effective informational teaching and learning activities within a specific subject area (Zhang and Wang, 2019).

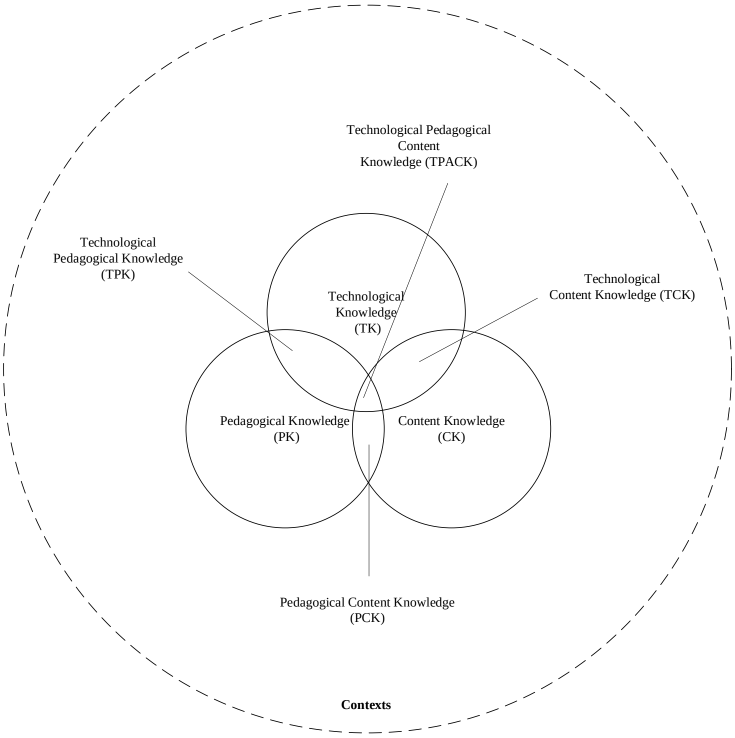

Fig. 2: The TPACK framework

2.3. Process of constructing test models

To meet the development needs of national vocational education, DQTs in higher vocational colleges should not only have PK and industrial ability but also master modern teaching concepts and methods and carry out diversified teaching activities and teaching research. MOE (2022a) issued the Notice on the Identification of DQTs in Vocational Education, which clearly states in its appendix "Basic Standards for 'Double-Qualified' Teachers in Vocational Education" that DQTs in higher vocational colleges should have corresponding theoretical and practical teaching competence, master advanced teaching concepts and techniques, and actively participate in teaching reform and research. They can effectively use modern information technology for teaching and learning, and they can use various teaching methods.

The teaching competence of DQTs in vocational education is a multidimensional concept, and teaching competence, practical competence, research competence, and innovation competence are considered to be the essential competencies of DQTs. Han et al. (2021) categorized the teaching competencies of DQTs in vocational education into six components, namely, curriculum development (CD), curriculum teaching (CT), professional knowledge (PK), occupational ability (OA), information literacy (IL), and research and development (RD). These factors are interrelated and mutually reinforcing, constituting the teaching ability of DQTs.

CD is the process of improving learning outcomes to meet student needs, and it includes elements such as educational philosophy, goals, objectives, learning experiences, pedagogical resources, and assessment methods that constitute a particular educational program (Alsubaie, 2016). In vocational education, a work process-based systematic CD model, which requires teachers to analyze, summarize, transform, and design typical work tasks and occupational competencies to form learning areas and learning contexts and organize them organically into a curriculum system, is proposed. According to the analysis of job tasks and vocational competencies, the curriculum should be set up according to the vocational competencies of different levels and categories, and the relationships and sequences between the courses should be determined. The DQTs in higher vocational colleges should have such CD ability.

CT is an essential aspect of the teaching competence of DQTs in higher vocational colleges. According to Marco-Bujosa et al. (2017), CT refers to how teachers use curriculum materials to plan and implement teaching activities to achieve teaching objectives and promote student learning. CT ability includes three abilities: teaching design, teaching implementation, and teaching evaluation (Li, 2024).

PK refers to the high level of knowledge structure, pedagogical competence, and professional development initiatives demonstrated by teachers in the teaching process (Cai et al., 2023). Teachers can flexibly apply knowledge of technology, pedagogy, content, and space to plan and implement instructional activities (Kali et al., 2019). Han et al. (2021) argued that teachers' PK consists mainly of professional theoretical knowledge, professional practical knowledge, and professional reflective knowledge.

OA means that DQTs should keep abreast of industrial development trends and industry talent needs; have related work experience or practical experience in enterprises; understand the relationship between the specialties they teach and the industry; be able to communicate and cooperate with industry enterprises and social organizations effectively; understand industrial development, industry needs and changes in occupational positions; and promptly incorporate new technologies, techniques, and specifications into teaching (MOE, 2022a).

IL involves effectively retrieving and evaluating information to solve problems and make decisions. Informationally literate people can learn to learn since they know how to access, organize, use, and disseminate information. Teachers should have IL skills and be capable of helping students develop IL skills (Sural and Dedebali, 2018). According to the Specification for Digital Campus in Vocational Institutions (MOE, 2020), teachers should have the following IL: 1) They can improve the effectiveness and level of teaching using information technology. 2) They can use information technology for online learning to enhance professional competence and "double-qualified" quality. 3) Information technology can support online cooperation and innovation to promote industry-education integration and school-enterprise cooperation. 4) They can use information technology to guide students and cultivate their IL and vocational information competence. 5) They can use information technology to make excellent educational evaluations and improve scientific and effective evaluations. Han et al. (2021) concluded that teachers have five main aspects of IL: awareness and attitudes, knowledge and technology, application and innovation, RD, and social responsibility.

The RD ability of teachers is an essential component of teachers' professional competence (Lavonen, 2016), which refers to the teaching and research ability and high moral quality of DQTs, their professional identity in higher education, and their strong "double-qualified" development concept. Policy documents issued by MOE (2019b), such as the implementation plan for national vocational education reform in 2019, the Opinions of MOE (2019b) of the Central Committee of the Communist Party of China on Comprehensively Deepening the Reform of Teacher Construction in the New Era (MOE, 2018), the Guidance Opinions of the Ministry of Education on Deepening the Reform of the Teacher Assessment and Evaluation System of Colleges and Universities (MOE, 2016), and the Implementation Plan for Deepening the Reform of DQTs Construction in Vocational Education in the New Era issued by the MOE (2019a), all propose enhancing the teaching abilities of vocational education teachers, especially the ability to teach research and professional development.

The six components proposed by Han et al. (2021), including CD, CT, PK, OA, IL, and RD, provide a comprehensive framework for understanding the multifaceted nature of teaching competencies for DQTs in vocational education. These components can be used as six factors for the teaching ability of "double-qualified" vocational education teachers, constituting a six-factor model, as shown in Fig. 3.

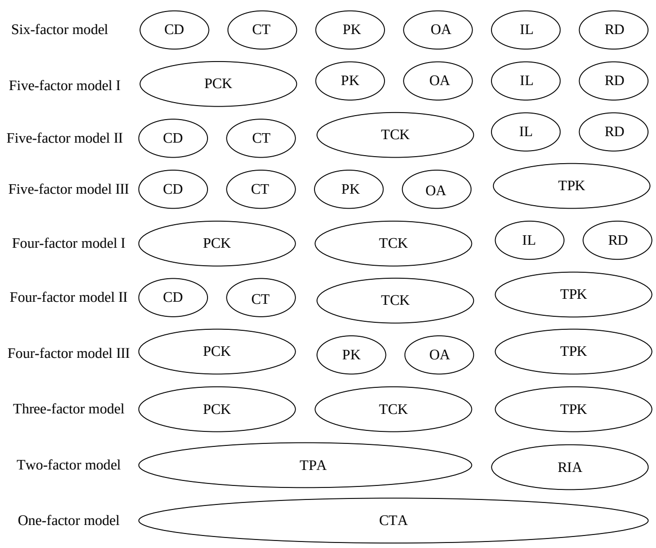

Fig. 3: Components of the models and their development

Transitioning to five-factor models, the first simplification occurs. In the five-factor model, I see the merging of CD and CT into PCK, representing a fusion of curriculum planning and delivery with a focus on the use of IT in subject-specific instructional content. Conversely, five-factor model II consolidates PK and OA into TCK, emphasizing the blend of PK with IT within the professional scope. Five-factor Model III converges IL and RD into TPK, underscoring the integration of IT with pedagogical practices. The subsequent four-factor models continue the theme of integration. In the four-factor model, I combine the factors of PK and OA from the previous iteration into TCK, echoing a continued emphasis on professional content and skills interfaced with IT. Four-factor Model II condenses the IL and RD factors from its five-factor predecessor into TPK, focusing on pedagogical strategies enabled by technology. Four-factor Model III synthesizes CD and CT into PCK, highlighting the interplay between IT and instructional content.

The three-factor model aggregates the competencies further, embodying PCK, TCK, and TPK. Here, the integration becomes more pronounced, blending IL and research development from the preceding four-factor model into TPK, a factor that represents the holistic integration of technology with pedagogical methods and content.

In a more pronounced abstraction, the two-factor model distills competencies into Teaching and Practice Ability (TPA) and Research and Innovation Ability (RIA). TPA encapsulates elements pertaining to subject content and methods, while RIA focuses on the application and innovation of IT in educational research.

Finally, the one-factor model encapsulates all preceding competencies into a single comprehensive teaching ability (CTA) for DQTs in vocational education. This factor is an overarching abstraction that portrays the teacher's ability to integrate IT across various levels and aspects of curriculum instructional activities, denoting a simplified yet broad model of teaching competencies.

Table 1 is the model construction process of the six-factor test model and its derivative test model for the teaching competency of DQTs in vocational education. We will continue the validation analysis of the test model and the discussion of the questionnaire constructs and the results. To test the effectiveness of different testing models in evaluating the teaching competence of DQTs in higher vocational colleges and to choose the most appropriate testing model, the following four research hypotheses are proposed.

H1: The six-factor model can best reflect the multidimensionality and complexity of DQTs' teaching ability in higher vocational colleges.
H2: The five-factor model I, five-factor model II, and five-factor model III are not as good as the six-factor model in terms of fit and explanatory power.
H3: The fit and explanatory power of the four-factor model I, four-factor model II, and four-factor model III are not as good as those of the six-factor and five-factor models.
H4: The three-factor model, two-factor model, and one-factor model are better than the six-factor model, five-factor model, and four-factor model in terms of fit and explanatory power.

3. Methodology

3.1. Research design

This quantitative study aimed to develop and validate a questionnaire assessing the teaching competencies of DQTs in Chinese higher vocational colleges. The questionnaire items were based on the three-level indicators by Li (2024). The questionnaire was distributed to DQTs from eight Chinese vocational colleges through both online and offline channels.

The data was evaluated using software programs known as SPSS and Amos. Initially, we examined fundamental statistics and assessed if our data adhered to a normal distribution. Subsequently, we employed the technique of factor analysis to scrutinize our questionnaire. In addition, we assessed the reliability of the questionnaire by calculating Cronbach's alpha, a statistical measure that evaluates its internal consistency. Ultimately, we assessed the degree to which several models aligned with our data to determine the most effective model for gauging the teaching abilities of DQTs.

3.2. Sample size

Determining an appropriate sample size is crucial for ensuring the reliability and validity of the study's findings. According to Hair et al. (2010), the minimum sample size for conducting CFA should be 5-10 times the number of observed variables (questionnaire items). In this study, the questionnaire consists of 25 items, which would require a minimum sample size of 125-250 respondents based on this rule of thumb. However, to obtain more precise estimates and to account for potential missing data or invalid responses, a larger sample size is necessary. Kline (2023) suggested that a sample size of at least 200 is generally recommended for structural equation modeling (SEM) analyses, such as CFA. Furthermore, Comrey and Lee (2013) provided a scale for determining the adequacy of sample sizes in factor analysis: 100 = poor, 200 = fair, 300 = good, 500 = very good, and 1,000 or more = excellent.

Considering these guidelines and the study's research objectives, a target sample size of 500 questionnaires was distributed to DQTs in Chinese higher vocational colleges. This target sample size falls within the "very good" range according to Comrey and Lee's (2013) scale and exceeds the minimum requirement of 200 recommended by Kline (2023) for SEM analyses.

Table 1: Process of constructing the teaching competence testing model for DQTs in higher vocational colleges

Test model	Factor	Construction process	New factor characteristics
Six-factor model	CD, CT, PK, OA, IL, RD	The teaching ability of DQTs in vocational education is divided into six factors	Each of the six constituent factors reflects the content and criteria for teachers to form and develop competencies at different levels of social practice, as well as teachers' knowledge and skills to integrate IT and teaching content and methods within specific subject areas
Five-factor model I	PCK, PK, OA, IL, RD	The two constituent factors of CD and CT were combined into one factor, PCK	This factor reflects teachers' knowledge and skills in integrating IT with instructional content and methods within a given subject area and the interaction between them
Five-factor model II	CD, CT, TCK, IL, RD	The two constituent factors of PK and OA are combined into one factor, TCK	This factor reflects teachers' knowledge and skills in integrating IT with professional content and skills within a given subject area and the interaction between them
Five-factor model III	CD, CT, PK, OA, Technological Pedagogical Knowledge (TPK)	The two constituent factors of IL and RD ability were combined into one factor, TPK	This factor reflects teachers' knowledge and skills in integrating information technology and instructional methods and strategies within a given subject area, as well as the interaction between them
Four-factor model I	PCK, TCK, IL, RD	The two constituent factors of PK and OA in the five-factor model I were combined into one factor, TCK	This factor reflects teachers' knowledge and skills in integrating IT with professional content and skills within a given subject area and the interaction between them
Four-factor model II	CD, CT, TCK, TPK	The two constituent factors of IL and RD ability in the five-factor model II were combined into one factor, TPK	This factor reflects teachers' knowledge and skills in integrating information technology and instructional methods and strategies within a given subject area, as well as the interaction between them
Four-factor model III	PCK, PK, OA, TPK	The two component factors of CD and CT in the five-factor model III were combined into one factor, PCK	This factor reflects teachers' knowledge and skills in integrating IT with instructional content and methods within a given subject area and the interaction between them
Three-factor model	PCK, TCK, TPK	The two constituent factors of IL and RD in the four-factor model I were combined into one factor, TPK	This factor reflects teachers' knowledge and skills in integrating information technology and instructional methods and strategies within a given subject area, as well as the interaction between them
Two-factor model	TPA, RIA	The six constituent elements were divided into two categories, namely, those related to subject content and methods (CD, CT, PK, and OA) and those related to information technology (IL, research, and development ability), and each category was combined into a single factor	These two factors reflect teachers' operational ability to master academic and applied skills and teachers' ability to understand, apply, and innovate in information technology and educational research
One-factor model	CTA of DQTs in vocational education	Combine all six component factors into one factor	This factor reflects teachers' knowledge and skills in integrating IT with instructional content and methods at different levels and aspects of curriculum instructional activities. This factor is an oversimplified and abstract model

3.3. Measurement

The questionnaire consisted of 25 questions covering six dimensions of DQTs' teaching ability in higher vocational colleges and was positively scored on a 5-point Likert scale, with 1 = no fit at all, 2 = little fit, 3 = basic fit, 4 = more fit, and 5 = full fit. Each dimension contains several measures, as shown in Table 2. The questionnaire was designed according to Li (2024), which covers the main dimensions of CTA that DQTs in vocational education should have in the information era.

4. Findings

4.1. Demographic

A total of 501 questionnaires were collected during the questionnaire survey, 454 of which were valid. There were 278 males (61.2%) and 176 females (38.8%); 405 (89.2%) were under 50 years of age; 393 (86.6%) had been teaching for less than or equal to 20 years; 414 (91.2%) were full-time teachers; 40 (8.8%) were part-time teachers; 147 (32.4%) taught professional theory courses; 64 teachers (14.1%) taught practical and internship guidance courses; 243 teachers (53.5%) taught professional theory and practical courses; 269 teachers (59.3%) had working experience in enterprises; 185 teachers (40.7%) did not have work experience in enterprises; 238 teachers (52.4%) were teachers of public institutions; and 216 (47.6%) were teachers of private institutions.

4.2. Descriptive statistics and normality test

Table 3 shows the results of the descriptive statistical analysis and normality test of the questionnaire on the current teaching ability of DQTs in higher vocational colleges. According to the descriptive statistics, 24 variables had mean scores between 3 and 4, only one variable, RD4, had a mean score greater than 4, and the scale score ranged from 1-5. Descriptive statistics were performed on the overall mean (OM) for each dimension, and based on the results, the quartile method was used to determine the criteria for categorizing teachers at high, medium, and low levels of teaching ability (Fernández and Martínez, 2022; Kane et al., 2011). Thus, the current level of teaching ability of the study population is medium (Table 4). The normality test for each measurement item was performed using skewness and kurtosis. According to the criteria proposed by Ghasemi and Zahediasl (2012), the absolute values of the skewness coefficient and kurtosis coefficient for each item were less than 1.96, indicating that the data distribution was not significantly different from the normal distribution at the $p<0.05$ level. The analysis results in Table 3 show that the skewness and kurtosis coefficients for each questionnaire item were in the range of ±1.96, indicating that the data for each measurement item conformed to the assumption of a normal distribution. The absolute values of the skewness and kurtosis coefficients for each of the items in this study were within the standard range of values.

Table 2: Questionnaire for the teaching ability of DQTs in higher vocational colleges

Dimension	Item
CD	CD1. I can define the course structure based on the job task and OA analysis table
	CD2. I can design and prepare a teaching schedule
	CD3. I can define a curriculum based on a job task and OA analysis table
	CD4. I can clarify the logical relationship between CD and talent development
CT	CT1. I can design teaching activities
	CT2.I can design teaching resources that support the teaching objectives and processes according to the teaching task and the teaching context
	CT3. I can use the appropriate teaching model well to carry out teaching activities
	CT4. I can maintain order in the classroom very well
	CT5. I can assess student learning in an objective manner
PK	PK1. I have a solid foundation of PK
	PK2. I can apply the basics of my profession very well
	PK3. I can apply knowledge of new technologies in my profession
OA	OA1. I can participate in activities organized by the college to provide services to the region
	OA2. I have certain practical skills in the industry within the classroom
	OA3. I have some practical skills in the industry outside of the on-campus classroom
	OA4. I have some practical skills in the off-campus industry
	OA5. I can participate in industry production activities and provide technical support
IL	IL1. I am good at evaluating and reflecting on information
	IL2. I have basic information skills
	IL3. I am good at collaborating and exchanging information with colleagues, students, industry personnel, etc.
	IL4. I can make innovations in teaching models
RD	RD1. I can conduct research on teaching and learning in vocational education
	RD2. I can improve my PK and practical skills through various ways and means
	RD3. I have developed a personal career growth plan
	RD4. I can develop students' awareness and ability to work ethically in the teaching process

4.3. Confirmatory factor analysis

We used several measures to check how well our models fit the data, including chi-square, RMSEA, GFI, IFI, TLI, and CFI. Generally, a chi-square value of less than three is good, and values around 0.9 for GFI, CFI, and IFI indicate a good fit. Values between 0.80 and 0.89 are also acceptable.

Given the results of the validated factor analysis model fit in Table 5, the six-factor model is considered the most appropriate choice. Specifically, $\chi 2/df = 2.438$, which falls within the excellent range (between 1-3), and RMSEA = 0.056, which falls within the acceptable range (less than 0.06) and meets the acceptable model criterion of RMSEA ≤ 0.06, as suggested by Hu and Bentler (1999). According to Hair et al. (2010) and Kline (2015), the model is deemed suitable when RMSEA ≤ 0.08. The GFI was 0.894, indicating an acceptable fit (>0.80). The IFI was 0.969, and the CFI was 0.969, both of which are excellent fit indicators (>0.90). A TLI of 0.964, which is greater than 0.95, is considered a good fit indicator (Hu and Bentler, 1999).

Table 3: Results of normality tests for descriptive statistics and measurement question items

Dimension	Item	M	SD	Skewness	S.E.	Kurtosis	S.E.	CFA factor loadings	Overall M	Overall SD
CD	CD1	3.65	0.95	-0.507	0.115	0.124	0.229	0.870	3.7186	0.87788
	CD2	3.79	0.96	-0.609	0.115	0.176	0.229	0.878		
	CD3	3.74	0.95	-0.484	0.115	-0.024	0.229	0.925		
	CD4	3.70	0.97	-0.380	0.115	-0.265	0.229	0.878		
CT	CT1	3.84	0.88	-0.514	0.115	0.409	0.229	0.842	3.9167	0.74409
	CT2	3.86	0.87	-0.410	0.115	-0.014	0.229	0.792		
	CT3	3.93	0.85	-0.505	0.115	0.338	0.229	0.875		
	CT4	3.96	0.85	-0.561	0.115	0.489	0.229	0.821		
	CT5	3.99	0.84	-0.708	0.115	0.740	0.229	0.829		
PK	PK1	3.98	0.86	-0.709	0.115	0.753	0.229	0.900	3.8803	0.77906
	PK2	3.93	0.84	-0.530	0.115	0.253	0.229	0.904		
	PK3	3.73	0.87	-0.402	0.115	0.147	0.229	0.810		
OA	OA1	3.72	0.94	-0.495	0.115	0.089	0.229	0.830	3.7617	0.83194
	OA2	3.87	0.88	-0.451	0.115	0.019	0.229	0.908		
	OA3	3.77	0.90	-0.327	0.115	-0.225	0.229	0.912		
	OA4	3.76	0.93	-0.412	0.115	-0.198	0.229	0.904		
	OA5	3.70	0.96	-0.417	0.115	-0.235	0.229	0.843		
IL	IL1	3.81	0.88	-0.444	0.115	0.089	0.229	0.839	3.8271	0.79099
	IL2	3.79	0.87	-0.355	0.115	-0.026	0.229	0.888		
	IL3	3.89	0.88	-0.547	0.115	0.203	0.229	0.881		
	IL4	3.81	0.86	-0.376	0.115	0.143	0.229	0.886		
RD	RD1	3.78	0.94	-0.414	0.115	-0.186	0.229	0.796	3.9515	0.79967
	RD2	3.94	0.92	-0.695	0.115	0.427	0.229	0.893		
	RD3	3.87	0.91	-0.517	0.115	0.131	0.229	0.917		
	RD4	4.22	0.86	-0.958	0.115	0.671	0.229	0.744		

Table 4: Categorization of the level of teaching ability of DQTs

Category	CD	CT	PK	OA	IL	RD
High	OM>4.5	OM>4.4	OM>4.3	OM>4.25	OM>4.5	OM>4.75
Medium	3.0≤OM≤4.5	3.4≤OM≤4.4	3.3≤OM≤4.3	3.0≤OM≤4.25	3.25≤OM≤4.5	3.25≤OM≤4.75
Low	OM<3.0	OM<3.4	OM<3.3	OM<3.0	OM<3.25	OM<3.25

Table 5: Fitted coefficients of the confirmatory factor analysis model

Measurement model	χ2	df	χ2/df	RMSEA	GFI	IFI	TLI	CFI
Six-factor model	633.912	260.000	2.438	0.056	0.894	0.969	0.964	0.969
Five-factor model I	1025.446	265.000	3.870	0.080	0.808	0.937	0.929	0.937
Five-factor model II	904.359	265.000	3.413	0.073	0.843	0.947	0.940	0.947
Five-factor model III	743.831	265.000	2.807	0.063	0.876	0.960	0.955	0.960
Four-factor model I	1264.063	269.000	4.699	0.090	0.773	0.918	0.908	0.917
Four-factor model II	1013.138	269.000	3.766	0.078	0.827	0.938	0.931	0.938
Four-factor model III	1134.707	269.000	4.218	0.084	0.794	0.928	0.920	0.928
Three-factor model	1372.522	272.000	5.046	0.095	0.760	0.909	0.899	0.909
Two-factor model	1801.872	274.000	6.576	0.111	0.697	0.873	0.861	0.873
One-factor model	1995.780	275.000	7.257	0.118	0.681	0.857	0.844	0.857

RMSEA: Root mean square error of approximation; GFI: Goodness of fit index; IFI: Incremental fit index; TLI: Tucker-Lewis index (also known as non-normed fit index, NNFI); CFI: Comparative fit index

These values indicate that the six-factor model is an excellent fit for the actual data and has good fitness. Compared with the other nine models, the six-factor model (Fig. 4) demonstrated superior fit. In addition, the six-factor model aligns with the theoretical assumptions of the DQTs' teaching ability evaluation index system and the TPACK framework in vocational education, leading us to conclude that it is more reasonable.

4.4. Internal consistency reliability

In this study, we measured the main factors in the form of scales, so checking the data quality of the measurement results is necessary to ensure that the subsequent analysis is significant. The internal consistency of each dimension was first analyzed using Cronbach's alpha coefficient reliability test. If a test has more than one concept or construct, alpha values should be calculated separately for each concept or construct rather than reporting alpha values for the test (Tavakol and Dennick, 2011). The Cronbach's alpha coefficient is between 0 and 1, and the greater the value of the test result coefficient is the greater the confidence level. Generally, α ≥ 0.7 is considered acceptable (Hair, 2009). A range of 0.7-0.8 is more plausible (Bland and Altman, 1997). Different ranges of acceptable alpha values have been reported from 0.70 to 0.95 (Tavakol and Dennick, 2011). In addition, Hair et al. (2010) argued that the two-by-two correlation between the question items used to assess the α coefficient needs to exceed 0.3, and the corrected item-total correlation (CITC) also needs to be greater than 0.5;

otherwise, the bad items should be excluded before the α coefficient is assessed (Hair, 2009).

According to the reliability results of this analysis (Table 6), the reliability coefficients of each dimension were in the range of 0.9-0.95. The two correlations between the items used to assess the alpha coefficients were greater than 0.5, exceeding 0.3, and the corrected item-total correlation (CITC) was greater than 0.7, exceeding the requirement of 0.5. Therefore, the questionnaire developed in this study has excellent internal consistency and reliability.

4.5. Validity test

This study analyzed the questionnaire's validity, including content validity, construct validity, and discriminant validity. Content validity assesses whether the questionnaire's test items accurately reflect the domains they are intended to measure, and expert opinion is the basis for establishing content validity (Kline, 2015). In this study, the questionnaire was designed with reference to Li (2024). We invited fifteen DQTs and three education experts to review and revise the questionnaire to ensure high validity and coverage. Construct validity pertains to the extent to which a test can measure theoretical constructs and traits, including whether scores measure a hypothesized construct that can only be measured indirectly through its indicators (Kline, 2015).

Under the assumption that the six-factor CFA model of the survey scale has a good fit, the reliability and validity of each dimension of the scale will be further examined. Since validity is fundamental in the research measurement model, both convergent and discriminant validity will be tested. Reliability tests rely on composite reliability (CR) and average variance extracted (AVE) for each variable. The CR should be 0.70 or higher, and the AVE should be 0.50 or higher (Ribeiro et al., 2017).

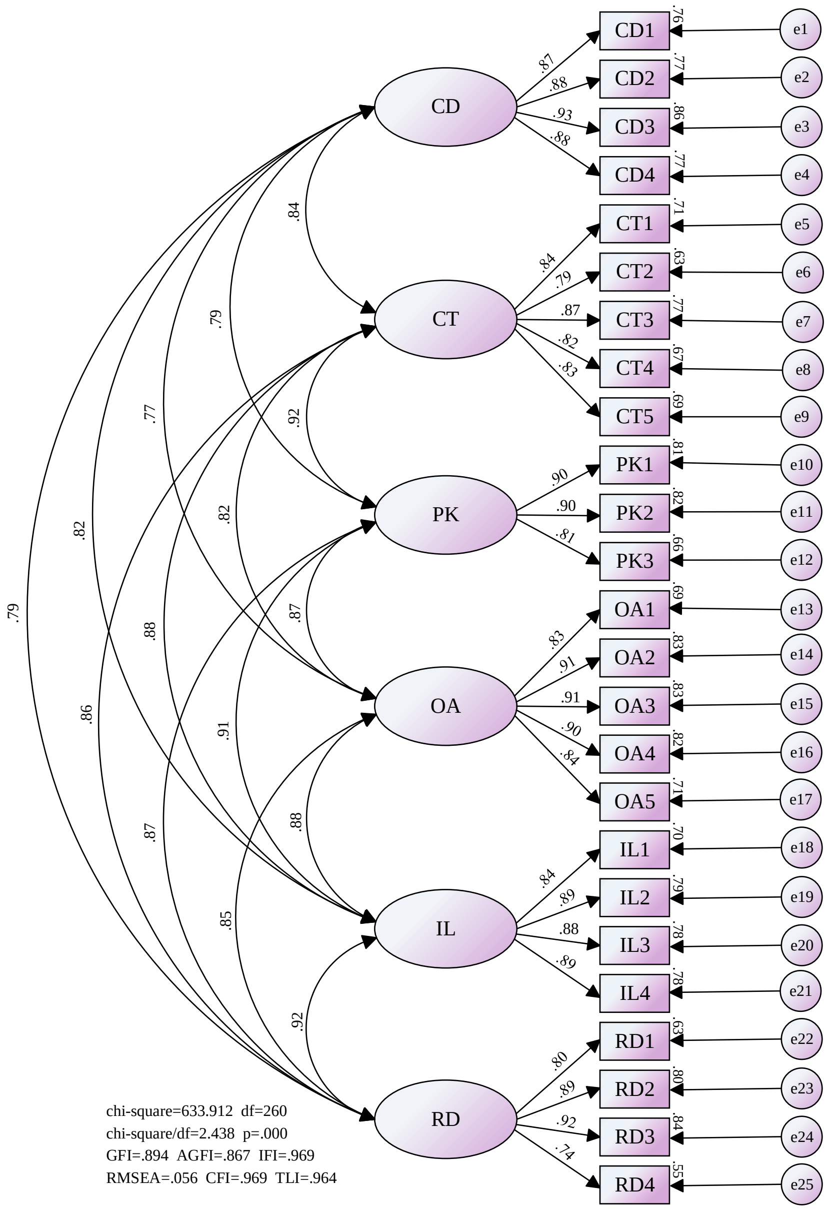

Fig. 4: Six-factor model confirmatory factor analysis

Table 6: Six-factor model interfactor correlation coefficient and internal consistency reliability of each factor

Dimension	Item	CD1	CD2	CD3	CD4		Corrected item-total correlation	Cronbach's alpha
CD	CD1	1.000					0.836	0.937
	CD2	0.760	1.000				0.841	
	CD3	0.803	0.810	1.000			0.879	
	CD4	0.771	0.774	0.813	1.000		0.847	
Dimension	Item	CT1	CT2	CT3	CT4	CT5		
CT	CT1	1.000					0.800	0.918
	CT2	0.715	1.000				0.755	
	CT3	0.724	0.691	1.000			0.828	
	CT4	0.663	0.629	0.766	1.000		0.786	
	CT5	0.696	0.632	0.697	0.704	1.000	0.776	
Dimension	Item	PK1	PK2	PK3				
PK	PK1	1.000					0.827	0.901
	PK2	0.831	1.000				0.840	
	PK3	0.705	0.720	1.000			0.745	
Dimension	Item	OA1	OA2	OA3	OA4	OA5		
OA	OA1	1.000					0.803	0.944
	OA2	0.748	1.000				0.865	
	OA3	0.731	0.849	1.000			0.870	
	OA4	0.735	0.816	0.839	1.000		0.882	
	OA5	0.739	0.729	0.739	0.799	1.000	0.821	
Dimension	Item	IL1	IL2	IL3	IL4			
IL	IL1	1.000					0.793	0.927
	IL2	0.768	1.000				0.859	
	IL3	0.729	0.795	1.000			0.843	
	IL4	0.708	0.781	0.788	1.000		0.827	
Dimension	Item	RD1	RD2	RD3	RD4			
RD	RD1	1.000					0.753	0.904
	RD2	0.712	1.000				0.835	
	RD3	0.725	0.820	1.000			0.842	
	RD4	0.598	0.674	0.675	1.000		0.710	

A construct is considered reliable in a measurement model if it has a normalized factor loading of at least 0.50 (Bagozzi and Yi, 2012). The testing process was performed by calculating the standardized factor loadings of each measurement question item on the corresponding dimension through the established CFA model. The CR formula of Kline (2015) and the AVE formula of Hair et al. (2010) were then calculated to obtain the CR and AVE values for each dimension. The calculation formulae are shown in (1) and (2).

$$\mathrm{CR} = \frac{(\sum \hat{\lambda}_i)^2 \hat{\Phi}}{(\sum \hat{\lambda}_i)^2 \hat{\Phi} + \sum \hat{\theta}_{ii}} \tag{1}$$

$$\mathrm{AVE} = \frac{\sum_{i=1}^{n} L_i^2}{n} \tag{2}$$

According to the results of the analysis shown in Table 7, it is evident that in this scale validity test, the CR values for each dimension ranged from 0.90 to 0.94, while the AVE values ranged from 0.69 to 0.79. These values surpass the recommended thresholds (or critical values) of 0.70 and 0.50, respectively, indicating strong combined reliability and convergent validity for each dimension. These findings suggest that the test model (Fig. 4) is valid and reliable.

Table 7: Convergent validity and combined reliability of each dimension of the questionnaire of DQT teaching ability in higher vocational colleges

Dimension	Item	Unstandardized factor loadings	Standard error	Z-value	P-value	Standardized factor loadings	CR	AVE
CD	CD1	1.000				0.870	0.937	0.789
	CD2	1.023	0.039	25.933	***	0.878		
	CD3	1.062	0.037	28.891	***	0.925		
	CD4	1.034	0.040	26.031	***	0.878		
CT	CT1	1.000				0.842	0.918	0.693
	CT2	0.935	0.045	20.605	***	0.792		
	CT3	1.005	0.042	24.001	***	0.875		
	CT4	0.947	0.044	21.538	***	0.821		
	CT5	0.949	0.043	21.948	***	0.829		
PK	PK1	1.000				0.900	0.905	0.761
	PK2	0.982	0.033	30.057	***	0.904		
	PK3	0.911	0.039	23.138	***	0.810		
OA	OA1	1.000				0.830	0.945	0.775
	OA2	1.019	0.040	25.263	***	0.908		
	OA3	1.050	0.041	25.344	***	0.912		
	OA4	1.075	0.043	25.017	***	0.904		
	OA5	1.038	0.046	22.416	***	0.843		
IL	IL1	1.000				0.839	0.928	0.763
	IL2	1.041	0.042	24.898	***	0.888		
	IL3	1.051	0.043	24.407	***	0.881		
	IL4	1.028	0.042	24.548	***	0.886		
RD	RD1	1.000				0.796	0.905	0.706
	RD2	1.101	0.049	22.459	***	0.893		
	RD3	1.121	0.048	23.264	***	0.917		
	RD4	0.854	0.049	17.515	***	0.744		

CR: Composite reliability; AVE: Average variance extracted; ***: P<0.001

As shown in Table 8, when compared to the six-factor model, each of the other nine models exhibited a lower degree of fit with the actual data and yielded statistically significant results in the chi-square significance test at a significance level of 0.001, which indicates that the model has discriminant validity.

Table 8: Results of the discriminant validity test of the DQT teaching ability questionnaire in higher vocational colleges

No.	Measurement model	χ2	df	χ2/df	RMSEA	GFI	IFI	TLI	CFI	Model comparison	Δχ2	Δdf
1	Six-factor model	633.912	260.000	2.438	0.056	0.894	0.969	0.964	0.969			
2	Five-factor model I	1025.446	265.000	3.870	0.080	0.808	0.937	0.929	0.937	2 vs 1	391.534***	5
3	Five-factor model II	904.359	265.000	3.413	0.073	0.843	0.947	0.940	0.947	3 vs 1	270.447***	5
4	Five-factor model III	743.831	265.000	2.807	0.063	0.876	0.960	0.955	0.960	4 vs 1	109.919***	5
5	Four-factor model I	1264.063	269.000	4.699	0.090	0.773	0.918	0.908	0.917	5 vs 1	630.151***	9
6	Four-factor model II	1013.138	269.000	3.766	0.078	0.827	0.938	0.931	0.938	6 vs 1	379.226***	9
7	Four-factor model III	1134.707	269.000	4.218	0.084	0.794	0.928	0.920	0.928	7 vs 1	500.795***	9
8	Three-factor model	1372.522	272.000	5.046	0.095	0.760	0.909	0.899	0.909	8 vs 1	738.610***	12
9	Two-factor model	1801.872	274.000	6.576	0.111	0.697	0.873	0.861	0.873	9 vs 1	1167.96***	14
10	One-factor model	1995.780	275.000	7.257	0.118	0.681	0.857	0.844	0.857	10 vs 1	1361.868***	15

***: P<0.001; RMSEA: Root mean square error of approximation; GFI: Goodness of fit index; IFI: Incremental fit index; TLI: Tucker-Lewis index (also known as non-normed fit index, NNFI); CFI: Comparative fit index

5. Discussion

This study synthesized Han et al.'s (2021) teaching competence evaluation index system for vocational education DQTs, Fo's (2022) essential competence qualities of vocational college DQTs, and the TPACK framework. Ten different test models were constructed to determine if the six-factor model can best reflect the multidimensionality and complexity of DQTs in higher vocational colleges. The confirmatory factor analysis results showed that the six-factor model outperformed the other nine models in terms of fit and explanatory power, supporting this hypothesis while rejecting the other hypotheses. The reasons for the non-applicability of the other models are their oversimplification or abstraction and inaccurate representation of teachers' pedagogical knowledge and skills in integrating information technology with pedagogical content and methodology in specific subject areas.

While this study demonstrates the applicability and robustness of the TPACK framework in evaluating the teaching competence of DQTs, it is important to discuss alternative frameworks such as the PCK framework, TPK, Self-Efficacy Theory, and competency-based education. PCK and TPK provide a narrower focus on the integration of pedagogy with content and technology, respectively. PCK, developed by Lee Shulman, emphasizes the blend of pedagogy and content knowledge. TPK, a subset of TPACK, focuses specifically on the interaction between technology and pedagogy. Bandura's Self-Efficacy Theory explores teachers' beliefs in their abilities to influence student engagement and learning, providing a psychological perspective on teaching competence. The competency-based education framework focuses on the specific skills and competencies required for effective teaching, which can be particularly useful in vocational education settings. Drawing on the concepts and methods of the TPACK framework, we explored the multidimensional structure and measurement instruments of the teaching competence of DQTs in higher vocational colleges, which can help us understand and assess how DQTs can effectively integrate information technology with teaching content and methods in specific subject areas.

The validated questionnaire developed in this study has significant practical implications for enhancing teacher training and professional development programs. First, vocational colleges can use this questionnaire to assess the current teaching competencies of their DQTs, identifying specific areas of strength and areas needing improvement. This assessment can inform the design of targeted professional development programs, ensuring that training is tailored to address specific competency gaps. Second, policymakers can utilize the findings from this questionnaire to develop standards and benchmarks for DQTs' teaching competencies. By establishing clear expectations and guidelines, vocational education systems can ensure that teachers are equipped with the necessary skills to integrate technology effectively into their teaching practices. Third, the questionnaire can serve as a tool for continuous professional development. Regular use of the questionnaire can help track the progress of DQTs over time, providing insights into the effectiveness of professional development initiatives and allowing for adjustments to be made as needed. Fourth, the questionnaire can be used to facilitate peer evaluations and self-assessments. By involving teachers in the evaluation process, colleges can foster a culture of continuous improvement and professional growth, encouraging DQTs to take ownership of their professional development.

This exploration helps researchers understand and assess how DQTs can effectively integrate information technology with teaching content and methods in specific subject areas. The current educational field focuses on exploring vocational education teachers' teaching competencies (Liu et al., 2021; Ismail et al., 2018). This study provides references and insights into the model's theoretical constructs and practical improvements for developing the questionnaire. However, there is a lack of comparison and integration among the different existing frameworks and a lack of validation and improvement of the teaching competency measurement tools for DQTs in higher vocational colleges. Therefore, this study examines the measurement properties of the teaching ability questionnaire for DQTs in higher vocational colleges. Specifically, we examined the internal consistency reliability, content validity, and structural validity of the questionnaire. For construct validity, we tested and compared the ten measurement models of the questionnaire using validated factor analysis. The results showed that all six-factor models achieved a better level of fit than the other nine measurement models and were consistent with the research hypotheses. The questionnaire has high internal consistency, reliability, and validity and can be used as a valid assessment instrument.

However, the correlation between individual factors needed to decrease for the six-factor model. However, this result may be due to the limitations of the confirmatory factor analysis method (You et al., 2017), and future studies may try to test the six-factor model further using exploratory structural equation modeling. This is because the exploratory structural equation modeling approach is considered one of the current methods for effectively addressing the limitations of confirmatory factor analysis (Asparouhov and Muthén, 2009). Furthermore, some entries of the six-factor model had lower factor loadings than others (e.g., CT2, RD1, RD4). The results of this study may also indicate that the relationships between some of the entries and the factors to which they belong are not significant enough, and future studies may need to revise some of the entries using more comprehensive research methods.

The reliability analysis of the scale showed that Cronbach's alpha of each factor was greater than 0.90, which indicated that the scale has high internal consistency and can effectively measure multiple dimensions of DQTs' teaching ability. However, the alpha value of one of the factors reached 0.94, which exceeded the maximum value of 0.90 suggested by Tavakol and Dennick (2011), which may mean that some of the questions under this factor are redundant and repeatedly measured for the same concept. Although this factor was derived from Li (2024), more detailed revision and validation of the questions under this factor are needed to improve the validity of the scale in the future. In addition, the correlation coefficients of the topics within each factor of the scale were high, except for the correlation coefficients between RD1 and RD4, which were below 0.6; the correlation coefficients between all other topics were above 0.6, reflecting that all these topics were closely related to the same factor.

This study provides meaningful findings for exploring the measurement and assessment of the teaching ability of DQTs in higher vocational colleges. However, there are also some unavoidable limitations. First, this study has a relatively small sample size of only 454 DQTs from eight Chinese vocational colleges, which may not adequately represent the level and characteristics of DQTs' teaching competence in vocational colleges across China. Therefore, the conclusions of this study may have specific limitations. Second, this was a cross-sectional study in which the actual situation and structure of the teaching ability of DQTs in higher vocational colleges were examined, but the development process and influencing factors were not examined in depth. Additionally, this study did not adequately compare and analyze the teaching ability of DQTs of different types, regions, and disciplines and cannot reveal the dynamic changes and differences in the teaching ability of DQTs in higher vocational colleges.

Future studies should seek to increase the sample size and scope, encompassing a diverse range of DQTs from different types, regions, and disciplines in higher vocational colleges. This will enhance the study's universality and representativeness. Additionally, longitudinal research or tracking research methods should be adopted to delve into the development process and influencing factors of DQTs' teaching ability in higher vocational colleges, thereby revealing their dynamic changes and differences. Furthermore, various data collection and analysis methods, such as interviews, observations, and experiments, should be employed to gather additional information and evidence that can support or validate the study's conclusions, revealing essential details and intrinsic connections.

6. Conclusion

In this study, we developed and validated a teaching competence questionnaire for DQTs in Chinese vocational colleges. We conducted preliminary analyses of its reliability and validity, and the results indicated that the questionnaire exhibited high internal consistency, reliability, and validity. Among the ten comparative models, the six-factor model demonstrated a more reasonable fit and superior explanatory power compared to the other nine models. However, this study has some limitations and areas for improvement. First, the correlation coefficients between some of the factors are excessively high, potentially reducing the distinction between these factors. We recommend conducting a more comprehensive examination of the six-factor model using explanatory structural equation modeling in future research. Second, certain questions within the questionnaire exhibited low factor loadings, potentially diminishing the explanatory power of the factors. We suggest that these questions be subject to revision or deletion in future iterations of the questionnaire. Therefore, future studies should reassess the questionnaire’s validity and item performance prior to its application and implement necessary revisions based on the validation results.

Compliance with ethical standards

Ethical considerations

All participants provided informed consent before participating in this study. The data collected was anonymized and used solely for research purposes. Confidentiality and privacy were maintained throughout, with data access restricted to the research team.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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