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Validation of the TPACK Instrument in the Croatian Primary School Context

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ABSTRACT

This study aimed to validate a generic TPACK questionnaire within the Croatian educational context, involving 609 in-service subject teachers from five regions. The survey-based research included exploratory and confirmatory factor analyses. The resulting structure diverged from the original seven-factor model, yielding five factors: pedagogical knowledge (PK), technological knowledge (TK), content knowledge (CK), technological content knowledge (TCK), and technological pedagogical content knowledge (TPACK). Some items were excluded to enhance validity. Pedagogical and pedagogical content knowledge merged, as did technological pedagogical and technological pedagogical content knowledge. The final five-factor model exhibited strong psychometric properties, characterized by high internal consistency and a good fit to the data. Evidence of convergent and discriminant validity supports the distinct yet interconnected nature of the identified knowledge domains. Significant positive correlations were found between all constructs, with the strongest correlations between TPACK and TCK, and also between TPACK and TK. The findings underscore the contextuality of the TPACK framework, and therefore, they were discussed in relation to recent national educational initiatives as well as international indicators on digital competencies. These results contribute to understanding the TPACK framework in the Croatian context, supporting future research on teacher competencies in integrating technology into education.

Keywords: in-service teachers, educational technology integration, factor analysis, teacher competencies, measurement validation

1. Introduction

In preparing students for the labor market, teachers are expected to effectively integrate information and communication technology (ICT) into the teaching process to enhance learning and contribute to the achievement of educational goals. To apply technology effectively in the classroom, teachers must connect knowledge from their subject area, the teaching methods they use in their specific classroom context, and technology's role in 21st-century learning. This concept is best explained through the Technological Pedagogical Content Knowledge (TPACK) model (Mishra & Koehler, 2006) in which the authors identify seven forms of teacher knowledge that emerge from the interaction of content, pedagogical, and technological knowledge. It is often visualized as a Venn diagram with three overlapping circles representing the types of knowledge and an outer circle symbolizing the context.

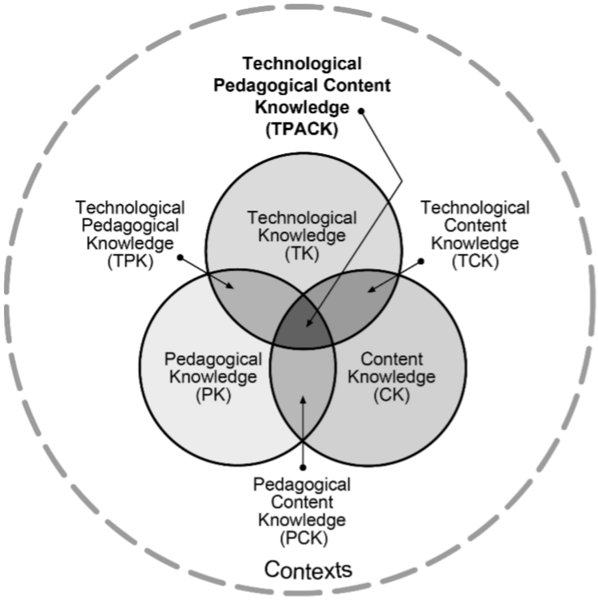

Figure 1. TPACK framework (Reproduced by permission of the publisher, © 2012 by tpack.org)

Building upon Shulman's earlier model of Pedagogical Content Knowledge (PCK) (Shulman, 1986, 1987), the authors (Koehler & Mishra, 2009; Mishra & Koehler, 2006) added the dimension of technology alongside content and pedagogy, and explained seven types of knowledge: content knowledge (CK) – knowledge of the subject area, including key concepts, theories, ideas, and organizational frameworks; pedagogical knowledge (PK) – knowledge of teaching and learning processes, including teaching methods, assessment, classroom management, and understanding of learning theories; technological knowledge (TK) – knowledge about using technology and digital tools, and the ability to adapt to technological changes; pedagogical content knowledge (PCK) – knowledge of teaching specific content adapted to the needs, prior knowledge, and interests of students; technological content knowledge (TCK) – understanding the relationship between content and technology and how technology can enhance the presentation and understanding of specific content; technological pedagogical knowledge (TPK) – knowledge about applying technology to improve teaching and learning while considering specific methods and strategies; and technological pedagogical content knowledge (TPACK) – knowledge that connects content, pedagogy, and technology for effective teaching in specific contexts. Although TPACK is often used as a model for the effective integration of technology into the teaching process, it is important to emphasize that, in fact, two knowledge dimensions within this model refer specifically to the integration of technology in teaching, TPK and TPACK (Graham, 2011). Together with the remaining dimensions, they provide insight into the complexity and dynamic nature of teacher knowledge.

Recently, an eighth dimension of contextual knowledge (XK) was proposed in the conceptualization of the model to encompass the specific knowledge required for teaching in particular contexts (Mishra, 2019; Petko et al., 2025). This dimension extends the original TPACK model by recognizing that effective teaching with technology is not universally applicable but depends on social, cultural, institutional, and situational factors. Although the TPACK model has been widely accepted and globally used as a theoretical framework in many studies, it has yet to gain significant recognition within the broader scientific community in the Republic of Croatia. In fact, only two TPACK-related studies have been conducted, both involving pre-service teachers (Dobi Barišić et al., 2019; Dobi Barišić & Brust Nemet, 2023). The curriculum reform in Croatia has further emphasized the role of technology through the adoption of the Cross-Curricular Topic Curriculum on the *Use of Information and Communication Technology* in primary and secondary schools, which promotes appropriate, responsible, and creative use of ICT across all educational domains (Ministry of Science and Education, 2019a). This has created a framework for applying the TPACK model in research within the Croatian educational context. Therefore, this study is primarily focused on validating the TPACK questionnaire in order to determine its applicability to a sample of in-service teachers within the Croatian education system.

1.1. Literature overview

TPACK research has employed quantitative, qualitative, and mixed-methods research approaches and has been conducted on samples of pre-service teachers, in-service teachers, university professors, online teachers, and teachers in professional development education. In quantitative research, various questionnaires have been employed, including general TPACK questionnaires, questionnaires for specific technologies, teaching methods, and content areas (Chai et al., 2016). The constructed questionnaires examined the interrelationships among TPACK factors, as well as the interrelationships with demographic variables, teacher beliefs, self-regulated learning, learning approaches and learning environment. Qualitative methods used in TPACK research can be classified into the following categories: observation, performance evaluation, open-ended questionnaires, and interviews (Koehler et al., 2012).

Previous validations of the TPACK questionnaire have focused on testing the reliability and validity of this self-assessment tool for teacher knowledge, as well as its adaptation to different contexts and cultures. Results indicate that the TPACK framework is widely accepted; however, challenges remain regarding its universal applicability. Using one or more statistical methods, such as exploratory factor analysis, confirmatory factor analysis, and structural equation modeling, several studies have confirmed the seven-factor structure in line with the theoretical model (Baser et al., 2016; Chai, Ng, et al., 2013; Deng et al., 2017; Dong et al., 2015; Lin et al., 2013; Pamuk et al., 2015; Sahin, 2011; Schmid et al., 2020; Schmidt et al., 2009; Valtonen et al., 2017). In some questionnaires used in these studies, more than seven factors were identified, as content knowledge was subdivided into multiple subscales depending on the sample (Chai et al., 2011; Schmidt et al., 2009). However, numerous studies have identified different numbers of factors in general TPACK questionnaires, TPACK questionnaires for specific subject areas, particular teaching methods, or the application of specific technologies: three factors (Archambault & Barnett, 2010; Luik et al., 2018), four (Chai et al., 2010; Jang & Tsai, 2012; Kabakci Yurdakul et al., 2012; Zelkowski et al., 2013), five (Karadeniz & Vatanartıran, 2013; M. H. Lee & Tsai, 2010; Semiz & Ince, 2012), six (Bostancıoğlu & Handley, 2018; Liang et al., 2013; Valtonen et al., 2017), eight (Canbazoğlu Bilici et al., 2013; Sang et al., 2016; Shinas et al., 2013) and nine factors (Ritzhaupt et al., 2016).

In Croatia, Dobi Barišić et al. (2019) validated the TPACK questionnaire developed by Schmidt et al. (2009) The *Survey of Pre-service Teachers' Knowledge of Teaching and Technology* (SPTKTT) on a sample of early childhood and primary education students. The factor structure was generally confirmed in line with the original model, although factor analysis results indicated certain differences in the distribution of individual items compared to the original validation, as well as contextual differences resulting from the organization of subject content in Croatian primary education (Dobi Barišić et al., 2019).

Considering the limited research on the knowledge required for successful technology integration in teaching in the Republic of Croatia, the contextual nature of TPACK practices, and the globally inconsistent results of TPACK questionnaire validations, it is necessary to validate the TPACK questionnaire on a sample of Croatian in-service teachers. This will enable further research on TPACK dimensions of knowledge within the Croatian educational context, which is especially important given the ongoing reform of the education system in Croatia and the adoption of subject and cross-curricular curricula (Ministry of Science and Education, 2019b). Since the 2021/2022 school year, all school classes and teachers in primary and secondary schools have been included in the education reform and are required to meet the educational expectations of the cross-curricular topic *Use of Information and Communication Technology*.

Therefore, this study aimed to validate the TPACK questionnaire to determine its applicability to a sample of in-service subject teachers in the Croatian education system. Through the validation of the instrument, the goal was to examine the factor structure of the TPACK model and to determine the reliability and validity of the measurement tool used, enabling future research into teacher competencies in the area of technology integration in the educational process.

2. Materials and Methods

2.1. Research Design

This cross-sectional study employed a quantitative research approach using a survey method. Surveying is considered the most appropriate method for assessing trends or characteristics of a specific population, determining relationships between variables, and comparing groups of respondents. It also enables the economical collection of data from geographically dispersed populations (Creswell, 2015). Additionally, it allows for rapid data collection from a large number of respondents while ensuring anonymity and facilitating the quantification of the collected data.

2.2. Participants

The study's target population consisted of primary school subject teachers in the Republic of Croatia. A cluster sampling strategy was employed considering the population's size and distribution, as well as the data collection method (Cohen et al., 2007). The study sample included subject teachers from randomly selected schools in five Croatian regions: Slavonia, Northern Croatia, the City of Zagreb, Istria and the Croatian Littoral with its Hinterland, and Dalmatia. In accordance with the available data, schools in both urban and rural areas, including island settlements, were included, with schools in each area selected randomly.

Due to the anticipated lower response rate in online surveys, a larger number of schools was selected than would be needed if all teachers responded. From the list of primary schools provided by the Ministry of Science and Education, 70 schools were randomly selected out of a total of 862 main schools and 1,101 branch schools in the 2021/2022 school year. A total of 651 teachers responded, which constitutes a representative sample for the target population of 16,518 subject teachers in Croatia (Primary and Secondary Schools, Croatian Bureau of Statistics). Further analysis of the dataset resulted in the removal of incomplete responses, resulting in a total of 632 participants. A statistical analysis was then conducted to remove multivariate outliers where 23 participants exceeded the critical value in the Mahalanobis distance analysis ($\chi 2$ (42) = 74.576, p = 0.001). Consequently, the final dataset used for statistical analysis included 609 teachers.

2.3. Instrument

In this study, teachers' self-assessments of their knowledge were examined in accordance with the components of the TPACK model, which include the following dimensions: (1) pedagogical knowledge, (2) content knowledge, (3) technological knowledge, (4) pedagogical content knowledge, (5) technological content knowledge, (6) technological pedagogical knowledge, and (7) technological pedagogical content knowledge. The results for each of these dimensions were calculated as the arithmetic mean of the scores of the respective items within each subscale. Since responses to the items were rated on a scale from 1 to 5, the values of each dimension also range within this interval.

In line with the study's aim and the operationalization of the research tasks, a questionnaire was constructed, consisting of two parts: sociodemographic data of the teachers and the TPACK scale. The part of the questionnaire related to sociodemographic data included nine multiple-choice questions covering gender, age, years of work experience in the profession, school location, initial education, educational field, professional advancement, and participation in professional development.

The TPACK scale was translated and adapted from a questionnaire developed by Schmid et al. (Schmid et al., 2020). To enable broader studies that would include teachers from various subject areas and educational levels, the authors constructed a scale in which most items were adapted or taken from previously validated questionnaires (Chai et al., 2011; Schmidt et al., 2009; Valtonen et al., 2017), while the authors themselves created some items based on existing literature and definitions. Earlier versions of TPACK instruments were generally applicable to specific populations of students or teachers who taught individual subjects and were focused on specific technologies or teaching methods. Therefore, the authors designed generically worded items to create a shortened version of the TPACK scale (28 items), aiming to reduce respondents' cognitive fatigue and facilitate the combination with other scales and applicability across a diverse teacher population.

Considering the specific characteristics of the sample within the Croatian education system and the fact that the TPACK questionnaire was being applied to teachers from various subject areas for the first time without being combined with other scales, a longer version of this generic questionnaire was selected. This version contains 42 items instead of 28. It was assumed that the longer version would provide better coverage of all TPACK construct dimensions, greater measurement reliability and validity, and better potential for factor analysis to effectively examine the structure of the measured construct in the national Croatian context. The longer version of the questionnaire contains 42 statements distributed across seven subscales: pedagogical knowledge (7 items), content knowledge (6 items), technological knowledge (7 items), pedagogical content knowledge (6 items), technological pedagogical knowledge (5 items), technological content knowledge (6 items), and technological pedagogical content knowledge (5 items). Each statement was rated on a five-point Likert scale, where respondents assessed their level of agreement with the statements (1 – strongly disagree; 2 – mostly disagree; 3 – neither agree nor disagree; 4 – mostly agree; 5 – strongly agree).

The content validity of the TPACK questionnaire was established during the translation and adaptation process. A university professor of pedagogy, two English language professors, and a subject teacher participated in the translation of the TPACK scale into Croatian. After harmonizing the translation, a pilot test was conducted with a small group of respondents. The aim was to obtain feedback on the clarity of questions and items to eliminate potential ambiguities and assess the time required to complete the questionnaire (Cohen et al., 2007). The pilot included eight subject teachers from the educational institution where one of the author works. Based on participant feedback, no major content ambiguities were identified. Two respondents suggested adding the word "digital" to the term "technology" in statements related to technological knowledge to clarify the concept. Although it was stated in the introductory note of the technological knowledge subscale that the statements referred to digital technologies (computers, tablets, mobile phones, the internet, etc.), the suggestion was accepted to include the word "digital" in the item wording for greater clarity. A professor of Croatian language also provided several stylistic improvement suggestions, which were incorporated into the final version of the questionnaire. A professor of Croatian language and literature proofread the translated and revised questionnaire.

2.4. Procedures

The survey was conducted online, considering the advantages and limitations of this data collection method. Online questionnaires enable the rapid and efficient collection of a large amount of data; however, they may also result in lower response rates and are more likely to reach respondents who have internet access and possess digital technology skills (Menon & Muraleedharan, 2020). Nevertheless, the use of an anonymous online questionnaire increases the level of confidentiality, as no third parties are involved in the distribution or collection process, unlike with traditional paper-based versions. The questionnaire was created using the digital application Microsoft Forms, which enabled easy distribution and systematic collection of participant responses.

In May and June of 2022, contact was established with principals of the 70 selected primary schools in five regions of the Republic of Croatia. According to the data available on the official website of the Ministry of Science and Education, initial telephone conversations were held with the principals to explain the purpose, goal, and procedures of the research. Principals of 68 schools agreed to participate in the scientific research, committing either personally or through school pedagogues to forward the online survey to subject teachers via the school's established online communication channels (e-mail, Microsoft Teams, or WhatsApp). The principals of two contacted schools declined participation.

Following the initial phone call, an email was sent to those who agreed to participate, containing brief information about the research and a link to the online questionnaire. The Ethics Committee of the University of Zadar issued approval for conducting this study, confirming its compliance with ethical standards and the appropriateness of the methodological procedures used during data collection and analysis.

2.5. Statistical analysis

Descriptive statistical parameters were determined for all variables used in this study (arithmetic mean [M], standard deviation [SD], minimum [Min] and maximum [Max] measurement values, skewness, and kurtosis of the distribution). To determine the factor structure of the TPACK questionnaire, exploratory factor analysis (EFA) was conducted on the first random subsample ($n = 312$). The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity (BTS) were applied prior to factor extraction to ensure that the data were suitable for EFA (Field, 2009). Multivariate outliers were identified by Mahalanobis distance, while multicollinearity was assessed through the correlation matrix and the Variance Inflation Factor (VIF), with values <5 considered acceptable. Principal Axis Factoring (PAF) was used for factor extraction, while the number of factors was determined using the Guttman-Kaiser criterion (eigenvalue > 1), Scree test (Cattell, 1966) and parallel analysis (Horn, 1965). While the Scree test is a visual method, parallel analysis establishes a criterion for factor extraction by comparing the eigenvalues from the actual data with those from randomly generated data sets with the same parameters (O'Connor, 2000). In this case, SPSS syntax was used: the factor was retained if the eigenvalue from the actual data was greater than the corresponding eigenvalue from the random data. Due to the assumption that the factors would be correlated, oblique rotation (Promax) was applied to enable a more realistic interpretation. Pattern coefficients from the Promax rotation were used to evaluate item-factor relationships, with items excluded if communalities were < 0.30, loadings < 0.40, or cross-loadings > 0.30 (Hair et al., 2010). Confirmatory Factor Analysis (CFA) using the Maximum Likelihood Estimates (ML) technique was conducted on the second random subsample ($n = 297$) to examine the stability of the factors obtained through EFA. A minimum standardized factor loading of 0.50 was used as the threshold for retaining items in the CFA model (Hair et al., 2010) Standard goodness-of-fit indices and their recommended values were used: $\chi^2/df < 3$, RMSEA (Root Mean Square Error of Approximation) ≤ 0.06, SRMR (Standardized Root Mean Square Residual) ≤ 0.05, TLI (Tucker–Lewis Index) ≥ 0.90, and CFI (Comparative Fit Index) ≥ 0.90 (Hooper et al., 2008). Convergent and discriminant validity were assessed through reliability coefficients and the following thresholds: AVE (Average Variance Extracted) ≥ 0.5, CR (Composite Reliability) > 0.7, and CR > AVE, indicating acceptable convergent validity. Discriminant validity was considered satisfactory if the correlation between factor scores was significant and if the correlation coefficient was lower than the square root of the corresponding AVE (Fornell-Larcker criterion). Additionally, the Heterotrait-Monotrait ratio (HTMT) ≤ 0.85 was used. To further support discriminant validity, the maximum shared variance (MSV) and average shared variance (ASV) were calculated, with the criterion that AVE should exceed both MSV and ASV for each construct. Internal consistency reliability in both EFA and CFA was determined using two coefficients: Cronbach's alpha (α) > 0.7 and McDonald's omega (ω) coefficient > 0.7 (McDonald, 1999). Since Cronbach's alpha is often criticized for underestimating internal consistency, omega was also calculated as an alternative. To determine the correlations between knowledge components according to the TPACK model, Pearson's correlation coefficient was used. The strength of correlations was evaluated using the following scale: 0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; 0.9, nearly perfect. The level of statistical significance was set at 0.05. All data were analyzed using SPSS 28.0 and AMOS 26.0 (SPSS, Chicago, IL, USA).

3. Results

3.1. Sociodemographic Characteristics

The study was conducted on a sample of 609 participants, with the majority being female (82.9% women and 17.1% men). Regarding age, the most represented categories were between 30 and 39 years (32.5%) and between 40 and 49 years (30.7%), followed by the 50- to 59-year-old age group (23.2%). Participants under the age of 30 made up 9.4% of the sample, while those over 60 were the least represented (4.3%). In terms of work experience, most participants had between 11 and 20 years of experience (32.2%), followed by those with 6 to 10 years (20.5%) and 21 to 30 years (20.5%). A total of 16.91% had less than five years of experience, and the smallest group included those with more than 30 years of teaching experience (9.9%). With respect to educational fields, most participants taught in the language and communication area (34%), followed by the social and humanistic area (12.6%), natural sciences (11%), interdisciplinary field (10.8%), mathematics (9.2%), technical and ICT field (11.2%), the arts (6.1%), and the least represented was the physical and health education field (5.1%).

3.2. Factor Structure – Exploratory Factor Analysis (EFA)

The skewness and kurtosis coefficients for all items range between −2 and +2, indicating the absence of univariate outliers in the data (see Appendix A). Regarding multivariate outliers, Mahalanobis distance analysis identified a total of 23 participants who exceeded the critical value ($\chi^2(42) = 74.576$, $p = 0.001$). Consequently, these participants were excluded from further analysis. Regrading multicollinearity, all correlation coefficients were below 0.9 (ranging from 0.07 to 0.8), with a large number above 0.3 ($n = 644$). Therefore, there is no indication of multicollinearity, and the data can be considered suitable for EFA. The Kaiser–Meyer–Olkin (KMO) measure was 0.949, and Bartlett's Test of Sphericity (BTS) yielded $\chi^2(861) = 9554.29$, $p < 0.001$. These results indicate the presence of a common structure among the variables, and thus, further analysis may be conducted.

Table 1 presents the results of factor extraction using the Principal Axis Factoring method, along with the corresponding total explained variance and initial eigenvalues. According to the Guttman-Kaiser criterion, a total of six factors with eigenvalues greater than 1 were extracted, accounting for 64.87% of the total explained variance. The scree plot did not indicate a clear point of inflection. However, although considered simple and widely used, the scree test relies on identifying sharp drops between eigenvalues and may sometimes suggest more than one point of inflection. Furthermore, the reliability of interpreting the scree plot is regarded as low. Additionally, the Guttman-Kaiser criterion overlooks sampling variability and is prone to overestimating the number of factors (Fabrigar et al., 1999). Consequently, the number of factors retained for further analysis was determined using the parallel analysis criterion, with Principal Axis Factoring as the extraction method. The parallel analysis revealed that the eigenvalues of the actual data exceeded those of the 95th percentile of randomly generated data for five factors, as shown in Figure 2. Accordingly, a five-factor solution was retained for further analysis.

total variance explained						
factor	initial eigenvalues			extracted sums of squared loadings		
	total	% of variance	cumulative %	total	% of variance	cumulative %
1	17.28	41.14	41.14	16.90	40.23	40.23
2	4.45	10.59	51.74	4.04	9.63	49.85
3	1.88	4.47	56.21	1.54	3.66	53.51
4	1.44	3.42	59.62	1.03	2.46	55.97
5	1.16	2.77	62.39	0.75	1.80	57.77
6	1.04	2.48	64.87	0.62	1.47	59.23

Table 1. Total explained variance and initial eigenvalues obtained using the Principal Axis Factoring Extraction method.

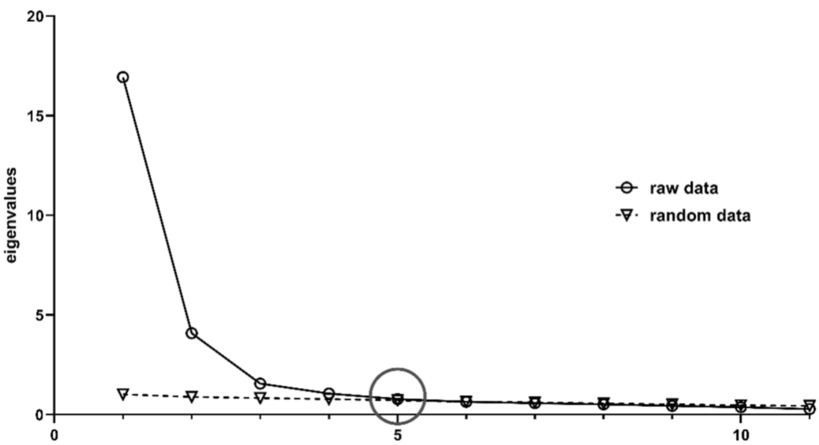

Figure 2. Cattell's Scree plot based on the results of the Parallel Analysis.

Table 2 presents the results of the EFA after Promax rotation. All retained items had communalities above 0.30. However, two items, TPK4 and TPK5, had factor loadings below 0.4 and were removed. Additionally, three items PCK2, CK2, and TCK6 were excluded due to cross-loadings on two or more factors (>0.3). As a result, a five-factor solution with 37 items was obtained, explaining a total of 64.22% of the variance. The first factor consisted of 12 items (explaining 41.57% of the variance) and was labelled PK. The second factor consisted of 7 items (11.01% of the variance) and was labelled TK. The third factor comprises eight items (4.94% of the variance) and was labelled TPACK. The fourth factor includes five items (3.70% of the variance) and was labelled TCK. Finally, the fifth factor consisted of 5 items (3% of the variance) and was labelled CK. Cronbach's alpha (α) and McDonald's omega (ω) coefficients indicated very good internal consistency reliability for the first four factors (ranging from 0.91 to 0.93). Slightly lower values were recorded for the CK factor (0.80).

item	factor				
	PK	TK	TPACK	TCK	CK
PK1	0.83				
PK5	0.74				
PK2	0.74				
PK7	0.68				
PCK5	0.65				
PK4	0.65				

PCK4	0.63				
PCK6	0.62				
PK3	0.60				
PK6	0.51				
PCK1	0.46				
PCK3	0.45				
TK7		0.96			
TK4		0.94			
TK5		0.93			
TK6		0.82			
TK2		0.75			
TK3		0.62			
TK1		0.58			
TPACK3			1.01		
TPACK2			0.88		
TPACK4			0.81		
TPACK1			0.72		
TPK1			0.61		
TPK2			0.54		
TPACK5			0.54		
TPK3			0.40		
TCK2				0.85	
TCK3				0.70	
TCK1				0.69	
TCK4				0.64	
TCK5				0.56	
CK6					0.72
CK5					0.59
CK4					0.58
CK3					0.56
CK1					0.47
α	0.91	0.93	0.93	0.91	0.80
ω	0.91	0.93	0.93	0.91	0.80

Legend: α – Cronbach's alpha; ω – McDonald's omega coefficient.

Table 2. Pattern coefficients and internal consistency reliability of subscales in the final model obtained through EFA analysis with promax rotation.

Table 3 shows the correlations between the factors obtained through Promax rotation. None of the correlations exceeded 0.7, which is favourable, as high correlations would suggest a strong linear relationship that could ultimately hinder the identification of distinct factors.

correlation matrix					
factor	**PK**	**TK**	**TPACK**	**TCK**	**CK**
PK	-				
TK	0.39	-			
TPACK	0.61	0.69	-		
TCK	0.37	0.61	0.70	-	
CK	0.62	0.40	0.60	0.47	-

Table 3. Interfactor correlation matrix of TPACK dimensions

3.3. Construct Validity – Confirmatory Factor Analysis (CFA)

Descriptive statistical parameters for all items retained after the EFA were examined prior to conducting the CFA. The skewness coefficients ranged from -3 to $+3$, and the kurtosis coefficients ranged from -7 to $+7$, indicating univariate normality of the distribution (see Appendix B). Regarding multivariate outliers, no participant exceeded the critical value in the Mahalanobis distance analysis. Thus, there were no multivariate outliers, and all participants were retained for further analysis. An inspection of the factor correlation matrix showed that all coefficients were below 0.9 (ranging from 0.51 to 0.84), indicating that multicollinearity was not a concern.

Table 4 presents the standardized factor loadings in the CFA. It is evident that all items have loadings above 0.5.

item	factor				
	1	2	3	4	5
PK1	0.68				
PK5	0.72				
PK2	0.68				
PK7	0.68				
PCK5	0.69				
PK4	0.72				
PCK4	0.74				
PCK6	0.73				
PK3	0.69				
PK6	0.57				
PCK1	0.75				
PCK3	0.73				
TK7		0.88			
TK4		0.85			
TK5		0.82			
TK6		0.82			
TK2		0.68			
TK3		0.81			
TK1		0.80			
TPACK3			0.87		
TPACK2			0.84		
TPACK4			0.88		
TPACK1			0.84		
TPK1			0.82		
TPK2			0.83		
TPACK5			0.80		
TPK3			0.83		
TCK2				0.77	
TCK3				0.79	
TCK1				0.71	
TCK4				0.82	
TCK5				0.84	
CK6					0.62
CK5					0.78
CK4					0.68
CK3					0.73
CK1					0.61

Table 4. Standardized Factor Loadings in CFA.

Table 5 presents the fit indices and χ^2 values for the five-factor model. The table includes three models. The first, original model shows a χ^2/df value below 3; however, the RMSEA, TLI, and CFI values are not satisfactory. Based on the analysis of modification indices, covariances were added between the items PK4 and PK5, TPACK2 and TPACK3, and TPK1 and TPK2. The model with added covariances shows acceptable values for nearly all parameters except for SRMR (> 0.05). Further analysis of the standardized residual covariances led to the exclusion of items CK1, TPACK5, PCK5, and PK6 from the analysis. As a result, a final five-factor model was obtained with all fit indices at satisfactory levels. The final five-factor model includes a total of 33 items (see Appendix C and Figure 3). Additionally, convergent and discriminant validity were assessed using reliability coefficients for the five-factor model.

Model	**χ2**	**df**	**χ2/df ≤ 3**	**RMSEA**			**SRMR**	**TLI**	**CFI**
				≤ 0.06	**LO90**	**HI 90**	**≤ 0.05**	**≥ 0.90**	**≥ 0.90**
original	1438.76	619	2.324	0.067	0.062	0.071	0.054	0.898	0.898
added covariances	1181.16	615	1.921	0.056	0.051	0.061	0.052	0.924	0.930
excluded CK1, TPACK5, PCK5, PK6	935.328	482	1.941	0.056	0.051	0.061	0.048	0.931	0.937

Legend: χ^2 – Chi-square; df – Degrees of freedom; RMSEA – Root Mean Square Error of Approximation; LO 90 – Lower bound of the 90% confidence interval for RMSEA; HI 90 – Upper bound of the 90% confidence interval for RMSEA; SRMR – Standardized Root Mean Square Residual; TLI – Tucker–Lewis Index; CFI – Comparative Fit Index

Table 5. Fit indices and χ^2 values for the five-factor model.

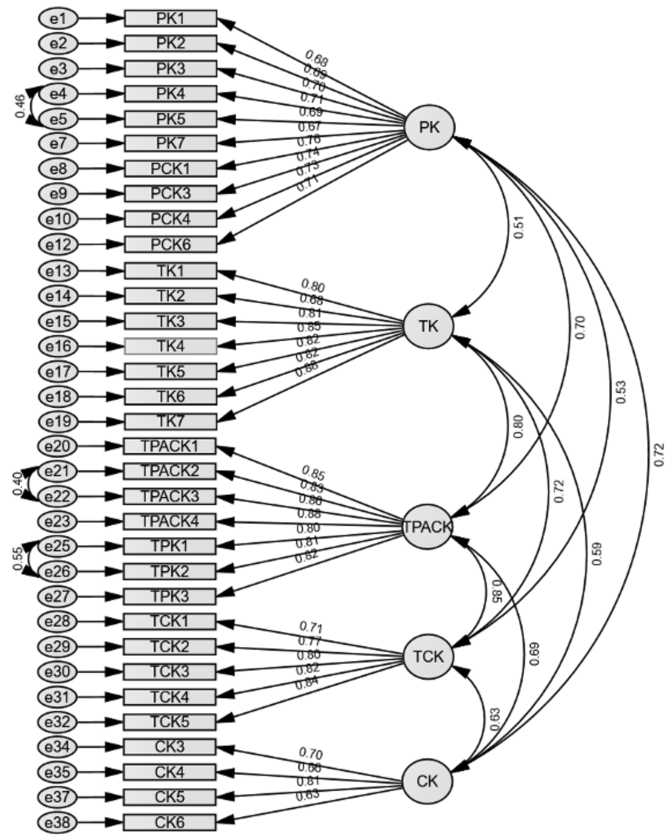

Figure 3. Confirmed five-factor model with 33 items based on CFA

3.4. Convergent and Discriminant Validity

Table 6 presents the results of the convergent and discriminant validity analyses along with the corresponding values. The average variance extracted (AVE) values for all factors were above 0.5, except for CK (0.49). Composite reliability (CR) values for each factor exceeded 0.7 and were greater than the respective AVE values. In addition, all Heterotrait–Monotrait ratio (HTMT) values were below the reference threshold of 0.85. To further support discriminant validity, MSV and ASV were also calculated. For four out of the five factors (PK, TK, TPACK, and CK), the AVE exceeded both MSV and ASV, supporting adequate discriminant validity. Although the AVE for the TCK factor was equal to its MSV, and its square root was slightly lower than the correlation with TPACK, this overlap is minor and theoretically expected. TCK and TPACK are closely related within the TPACK framework, where TCK is a core component of TPACK, which combines technological, pedagogical, and content knowledge. Importantly, the HTMT value between TCK and TPACK was well below the conservative 0.85 threshold, which supports acceptable discriminant validity. Additionally, all ASV values remained lower than their respective AVEs, further confirming discriminant validity across the model. Finally, the values of both internal consistency reliability coefficients were above 0.7, which is considered satisfactory.

factor	CR	AVE	MSV	ASV	α	ω	PK	TK	TPACK	TCK	CK
PK	0.91	0.50	0.48	0.36	0.91	0.89	**0.71**	0.46	0.64	0.47	0.60
TK	0.93	0.66	0.64	0.42	0.93	0.93	0.50	**0.81**	0.76	0.66	0.50
TPACK	0.94	0.71	0.64	0.55	0.95	0.95	0.69	0.80	**0.84**	0.77	0.60
TCK	0.89	0.62	0.62	0.40	0.89	0.89	0.49	0.66	0.79	**0.78**	0.55
CK	0.79	0.49	0.48	0.39	0.78	0.78	0.69	0.59	0.68	0.53	**0.70**

Legend: CR – Composite Reliability; AVE – Average Variance Extracted; MSV - maximum shared variance; ASV - average shared variance; square root of AVE on the diagonal (in bold); α – Cronbach's alpha; ω – McDonald's omega coefficient. The values above the diagonal are values from the heterotrait–monotrait (HTMT) validity analysis, while the values below the diagonal represent latent construct correlations (Fornell–Larcker matrix).

Table 6. Convergent and discriminant validity with reliability coefficients for the five-factor model.

3.5. Correlations between TPACK Model Constructs

Descriptive statistical parameters for the final model of the TPACK questionnaire are presented in Table 7. The results of the mean values show that respondents scored highest in PK and lowest in TCK. Correlations between the TPACK constructs are shown in Table 8. It is evident that statistically significant correlations exist between all constructs ($p < 0.01$).

construct	AS	(SD)	min.	max.	skew	kurt
PK	4.52	(0.42)	2.7	5	-0.60	-0.38
TK	4.12	(0.66)	1.86	5	-0.47	-0.35
TPACK	4.27	(0.55)	2.57	5	-0.36	-0.37
TCK	4.00	(0.66)	2.2	5	-0.08	-0.74
CK	4.47	(0.47)	2.75	5	-0.78	0.19

Legenda: M – Mean; SD – Standard Deviation; Min – Minimum score; Max – Maximum score; Skew – Skewness coefficient; Kurt – Kurtosis coefficient.

Table 7. Descriptive statistical parameters of TPACK questionnaire constructs ($n = 609$).

construct	PK	TK	TPACK	TCK	CK
PK	-				
TK	0.42**	-			
TPACK	0.63**	0.72**	-		
TCK	0.46**	0.64**	0.75**	-	
CK	0.61**	0.44**	0.58**	0.59**	-

Legend: ** – significant correlations at $p < 0.05$

Table 8. Pearson Product-Moment correlation between TPACK constructs.

4. Discussion

4.1. Factor analysis of the TPACK questionnaire

This study aimed to validate the TPACK questionnaire with a sample of in-service subject teachers within the Croatian educational system to confirm its factor structure and examine the reliability and validity of the applied measurement instrument. Unlike the findings of Dobi Barišić et al. (2019), who validated the SPTTK questionnaire (Schmidt et al., 2009) on a sample of Croatian pre-service teachers and early childhood educators and identified a nine-factor structure, this study, using the questionnaire developed by Schmid et al. (2020), which largely includes items from the original SPTTK, revealed a five-factor structure. These differences in factor structure can likely be attributed to the use of different instruments and samples (i.e., pre-service teachers and preschool teachers versus in-service subject teachers).

The merging of PK and PCK and TPK and TPACK constructs suggests a lack of clear distinction between these dimensions in how the items were formulated. Croatian subject teachers do not differentiate their general pedagogical knowledge (PK) from pedagogical content knowledge (PCK), i.e., knowledge specific to teaching particular subject matter. Similarly, they do not distinguish between TPK (knowledge of how to use technological tools to enhance teaching and learning) and TPACK (knowledge of how to integrate technology in teaching specific subject content effectively and constructively). This reflects how Croatian subject teachers perceive and apply pedagogical and technological pedagogical knowledge in an integrated and context-specific manner. As Croatian subject teachers are mainly trained within strong disciplinary context (e.g., science faculties, humanities faculties…), their perception of teaching knowledge may not clearly separate general pedagogical principles (PK) from pedagogical content knowledge (PCK) and general pedagogical technological principles (TPK) from its application in subject-specific context (TPACK). These results can be interpreted through cultural and systemic factors in Croatian education. In teaching subject methodologies, which are integral part of teacher education, integrated knowledge application is emphasized more than strict conceptual boundaries. Additionally, the findings may indicate theoretical limitations and ambiguities within the original TPACK framework, issues that have been highlighted by several scholars (Angeli & Valanides, 2009; Bos, 2011; Cox & Graham, 2009; Graham, 2011; Kimmons, 2015; Ritzhaupt et al., 2016). The lack of distinction between PK and PCK, as well as between TPK and TPACK, was also observed by Ritzhaupt et al. (2016) who validated Schmidt et al.'s (Schmidt et al., 2009) questionnaire on a sample of American pre-service teachers.

The merging of PK and PCK can also be interpreted within the context of limitations in Shulman's original PCK model (1986), upon which the TPACK framework is built. The boundaries between PK and PCK have been conceptualized differently over time and remain somewhat unclear (Gess-Newsome, 1999; Gess-Newsome et al., 2017; Lee & Luft, 2008). Difficulties distinguishing PK and PCK were also found in a study by Lee & Tsai (2010), conducted on a sample of Taiwanese primary and secondary school teachers using the TPAC-W questionnaire, which measured teachers' TPACK self-assessments in the context of web technologies. The merging of PK and PCK was similarly observed in studies involving pre-service teachers in the U.S. (Shinas et al., 2013), Singapore (Koh et al., 2010), Turkey (Semiz & Ince, 2012), and among 542 EFL teachers from nine countries (Bostancıoğlu & Handley, 2018). Zelkowski et al. (2013) encountered issues with the PCK construct in their exploratory factor analysis of a TPACK questionnaire among future mathematics teachers in the U.S. This construct, along with TPK and TCK, was entirely removed from the analysis due to cross-loading across different factors.

In the present study, validation of the questionnaire in the Croatian context revealed a clearly defined content knowledge (CK) factor despite removing several original CK items. This reflects the way subject teachers are educated at faculties focused on specific disciplines (e.g., language teachers at faculties of humanities, physics teachers at faculties of science, physical education teachers at faculties of kinesiology). In recent years some subject teachers have also been educated at teacher education faculties (classroom teachers with one subject specialization). In contrast to this finding, CK was combined with PK and PCK in some previous studies, such as those involving American online teachers (Archambault & Barnett, 2010) and pre-service teachers in Estonia (Luik et al., 2018). The persistence of a distinct CK factor in our study, contrasting with its merging with PK and PCK in U.S. and Estonian contexts may reflect systemic differences in teacher training priorities. Croatia's emphasis on traditional subject orientation could reinforce clear boundaries between content and pedagogical knowledge, whereas systems in the U.S. and Estonia that promote integrated and interdisciplinary teaching roles (Eisenschmidt et al., 2023; Mansilla & Lenoir, 2010) may blur these distinctions. Furthermore, the differences between Croatian and American results can be attributed to the contrasting educational traditions: Croatia aligns with the European, predominantly Germanic tradition of didactics, while the United States follows the Anglo-American tradition of curriculum and instruction (Matanović, 2017). Croatia was strongly influenced by the Germanic tradition that emphasizes professional subject competencies. On the other hand, the American educational paradigm is criticized for neglecting factual knowledge (Kansanen, 2002).

The technological knowledge (TK) construct also identified a clear distinction. Croatian teachers differentiate their knowledge of using specific digital technologies at the user level. In the Croatian educational system, toward the end of the 20th and the beginning of the 21st century, alongside the growing development of computer technologies, educators in many Croatian schools were offered opportunities for training and to obtain the European Computer Driving Licence (ECDL), an internationally recognized certification of digital literacy. Additionaly, significant contributions to the development of digital competences of teachers in Croatia were made by the e-School projects, implemented in two phases from 2018 to 2023 (CARNET, 2019), and the School for Life curricular reform implemented from 2018 to 2020. The e-School project facilitated comprehensive and systematic education in the application of digital tools and the integration of ICT in teaching, resulting in an increase in digital literacy and readiness for innovative pedagogical practices. The curricular reform further emphasized the importance of applying digital technologies through changes in teaching content and methods, encouraging the development of competences focused on active and creative learning (Ministry of Science and Education, 2019a). These contemporary efforts are supported by the research findings of this study, which indicates the strengthening of teacher knowledge dimensions, but also highlight challenges in their clear differentiation, confirming the need for continuous professional development and support within the educational system. Some earlier international studies indicate the need for further professional development of Croatian teachers. For example, TALIS (*Teaching and Learning International Survey*) results show that Croatian teachers express a need for further training in integrating technology into teaching (OECD, 2019), while DESI (Digital Economy and Society Index) reports indicate that Croatia, despite progress in basic digital skills, is still lagging in systematic digital transformation and development of ICT capacities in education (European Commission, 2023). These findings may partly explain the merging of the TPK and TPACK dimensions in the validation of the TPACK questionnaire. Although certain positive developments have been made in teacher education, it seems that some shortcomings in systematic education detected by TALIS and DESI research may make it difficult for teachers to clearly distinguish general technological pedagogical knowledge from its appropriate integration into subject content. The extraction of the TCK (Technological Content Knowledge) construct in this study is in contrast with some previous research. In several studies that demonstrated a departure from the original seven-factor structure, TCK was merged during factor analysis with other technology-related dimensions, for example, with the TPK (Liang et al., 2013), TPACK (Shinas et al., 2013), TPK and TPACK (Archambault & Barnett, 2010; Karadeniz & Vatanartıran, 2013; Koh et al., 2010; Liu et al., 2015), and with TK, TPK, and TPACK dimensions (Luik et al., 2018). This merging of TPK items with TPACK was also observed in studies by Koh et al. (2010), Karadeniz and Vatanartıran (2013), and Shinas et al. (2013). Research indicating the merging of technological dimensions may reflect highly integrated curricula that treat technology as an integral part of all subjects rather than a separate competency. The findings of this study, which indicate the extraction of the TCK construct and the merging of items from the TPK and TPACK subscales, are most similar to those reported by Lee and Tsai (2010).

In summary, the results of the TPACK questionnaire validation, which deviated from the original seven-factor theoretical model, are consistent with numerous international studies that identified either more or fewer factors than originally proposed. This suggests the presence of certain cultural and contextual differences in teachers' self-assessment of knowledge. Furthermore, the difficulties in distinguishing PCK from PK, as well as TK from other technology-related dimensions, observed in this study, are in line with findings from earlier studies conducted in American (Archambault & Barnett, 2010; Shinas et al., 2013; Zelkowski et al., 2013), Estonian (Luik et al., 2018), Singaporean (Koh et al., 2010), Taiwanese (Lee & Tsai, 2010) and

Turkish contexts (Karadeniz & Vatanartıran, 2013; Semiz & Ince, 2012). Given the subject-specific nature of TPACK knowledge, it is possible that the difficulty in confirming the original seven-factor model partially stems from the lack of attention to subject-area specificity. That is, the use of generically formulated questionnaire items, applied across samples of teachers from various disciplines, may not offer respondents a sufficient basis for clearly distinguishing between domains of knowledge.

4.2. Correlation analysis between TPACK constructs

All correlations between the TPACK knowledge dimensions were positive and statistically significant, consistent with the theoretical framework of the model. Weak correlations between the core knowledge dimensions PK and TK, as well as CK and TK suggest that these domains serve distinct roles and focus on different aspects of the teaching context. PK and CK showed a moderate correlation with each other (higher than with TK), reflecting the traditional interconnection between pedagogy and content during teacher education and professional development. In contrast, technology is perceived as a new variable and a relatively separate component. These results align with the findings of previous studies conducted on in-service teachers (Dong et al., 2015; Koh et al., 2014; Mohammad-Salehi & Vaez-Dalili, 2022), as well as on pre-service teacher education students (Koh & Chai, 2011; Valtonen et al., 2017). The weak correlations between PK and TK, and between CK and TK, are further supported by other research (Koh & Chai, 2011; Roig et al., 2015; Valtonen et al., 2017) which reported small to negligible associations between these constructs. In contrast, Soto and Herrera (2022) and Sofyan et al. (2023) emphasize a stronger correlation between CK and PK. It can be observed that correlations within the technological dimensions are generally higher than their correlations with the non-technological knowledge dimensions, except for TK and TCK, which showed a moderate correlation. This finding is consistent with the findings of Koh, Chai, and Tsai (2014) and Mohammad-Salehi and Vaez-Dalili (2022). However, previous research results in this area suggest a certain degree of variability, as some studies report a strong correlation between these two dimensions of knowledge (Soto & Herrera, 2022; Roig et al., 2015; Sofyan et al., 2023).

The relationship between the TCK and TPACK dimensions appears to be clearer, as many studies, including the present one, have found a strong correlation between them (Chai, Chin, et al., 2013; Dobi Barišić et al., 2019; Koh et al., 2014; Mohammad-Salehi & Vaez-Dalili, 2022; Soto & Herrera, 2022; Roig et al., 2015; Sofyan et al., 2023). These findings align with the transformative perspective on the TPACK framework, which suggests that hybrid dimensions have a greater influence on integrated teacher knowledge than the core components. The high correlation may stem from the fact that integrating technology into teaching requires knowledge of content-specific tools and that teachers with well-developed TCK are more motivated to experiment with technology in the classroom. This, in turn, can enhance their TPACK through reflection and experience. Although correlations are generally consistent with prior studies, inconsistencies in the strength of relationships among certain dimensions highlight the need for further research into contextual factors.

4.3. Recommendations and limitations

The results of the TPACK questionnaire validation highlight the challenges in developing a universal instrument capable of assessing all seven domains of knowledge defined by the TPACK model, applicable across diverse geographic and subject-specific contexts. Therefore, future research is encouraged to consider the previously discussed dimension of contextual knowledge. Specifically, the applied questionnaire did not include contextual knowledge, which Mishra (2019) later added to the original model. Future studies on teacher knowledge would benefit from incorporating this contextual dimension to gain a deeper understanding of the dynamics of teacher knowledge development, while also acknowledging the specific characteristics of the environment, students, curriculum, and resources. This, ultimately, may lead to more effective educational solutions. This study's main limitation lies in using self-assessment through the TPACK questionnaire. Self-assessments rely on participants' personal judgments and perceptions, which may introduce subjectivity and bias. Teachers may overestimate or underestimate their knowledge. Therefore, future research should combine self-assessment data with observations of how TPACK dimensions are applied in educational practice, as well as instruments that objectively measure teacher knowledge.

5. Conclusion

The validation of the TPACK questionnaire confirms that the framework is a useful tool for understanding and assessing the competencies of Croatian in-service teachers related to technology integration in teaching. The findings support a five-factor structure, pointing to localized interpretations of teacher knowledge domains. This outcome highlights the importance of adapting the TPACK theoretical construct to reflect educational traditions and teacher education pathways within the Croatian context. By integrating recent reforms, professional development initiatives and relevant international indicators, this study situates its results within current educational policy. The validation of the TPACK questionnaire in the Croatian educational context has opened the door to further research on TPACK knowledge dimensions among in-service teachers and to the integration of this instrument with other measurement tools and research approaches.

Appendix A: Descriptive statistical parameters for all items of the applied questionnaire (n = 312).

item	M	(SD)	min.	max.	Skew	Kurt
PK1	4.60	(0.52)	3	5	-0.74	-0.73
PK2	4.45	(0.58)	3	5	-0.48	-0.70
PK3	4.48	(0.55)	3	5	-0.42	-0.89
PK4	4.50	(0.59)	3	5	-0.72	-0.44
PK5	4.51	(0.58)	3	5	-0.70	-0.49
PK6	4.37	(0.63)	2	5	-0.54	-0.22
PK7	4.52	(0.58)	3	5	-0.71	-0.48
CK1	4.71	(0.46)	4	5	-0.91	-1.17
CK2	4.66	(0.48)	3	5	-0.76	-1.20
CK3	4.79	(0.41)	4	5	-1.45	0.11
CK4	4.38	(0.70)	2	5	-0.86	0.13
CK5	4.53	(0.59)	2	5	-0.96	0.41
CK6	4.21	(0.73)	2	5	-0.59	-0.11
TK1	4.32	(0.70)	3	5	-0.54	-0.84
TK2	3.85	(1.00)	1	5	-0.44	-0.64
TK3	4.27	(0.70)	2	5	-0.47	-0.63
TK4	4.24	(0.74)	2	5	-0.51	-0.69
TK5	3.88	(0.83)	2	5	-0.28	-0.56
TK6	4.21	(0.77)	2	5	-0.51	-0.76
TK7	4.07	(0.81)	2	5	-0.41	-0.68
PCK1	4.42	(0.58)	3	5	-0.37	-0.75
PCK2	4.34	(0.62)	3	5	-0.37	-0.66
PCK3	4.50	(0.57)	3	5	-0.57	-0.69
PCK4	4.60	(0.55)	3	5	-0.95	-0.16
PCK5	4.67	(0.47)	4	5	-0.71	-1.51
PCK6	4.60	(0.52)	3	5	-0.76	-0.71
TPK1	4.25	(0.66)	3	5	-0.32	-0.76
TPK2	4.28	(0.64)	3	5	-0.31	-0.68
TPK3	4.30	(0.65)	2	5	-0.46	-0.37
TPK4	4.37	(0.65)	3	5	-0.56	-0.66
TPK5	3.94	(0.94)	1	5	-0.59	-0.11
TCK1	4.18	(0.75)	2	5	-0.49	-0.53
TCK2	3.93	(0.82)	2	5	-0.22	-0.77
TCK3	3.91	(0.78)	2	5	-0.13	-0.70
TCK4	3.90	(0.82)	2	5	-0.18	-0.77
TCK5	4.16	(0.73)	2	5	-0.36	-0.70
TCK6	4.39	(0.66)	2	5	-0.70	-0.25
TPACK1	4.16	(0.66)	2	5	-0.32	-0.23
TPACK2	4.36	(0.62)	3	5	-0.43	-0.66
TPACK3	4.31	(0.61)	3	5	-0.27	-0.63

TPACK4	4.23	(0.67)	2	5	-0.36	-0.53
TPACK5	3.95	(0.87)	2	5	-0.41	-0.59

Legend: M – Mean; SD – Standard Deviation; Min – Minimum score; Max – Maximum score; Skew – Skewness coefficient; Kurt – Kurtosis coefficient

Appendix B: Descriptive statistical parameters for all items of the applied questionnaire after EFA (n = 297).

item	M	(SD)	min.	max.	Skew	Kurt
PK1	4.57	(0.52)	3	5	-0.58	-1.04
PK2	4.47	(0.59)	2	5	-0.69	0.06
PK3	4.44	(0.61)	2	5	-0.80	0.53
PK4	4.52	(0.57)	3	5	-0.68	-0.56
PK5	4.49	(0.61)	3	5	-0.79	-0.37
PK6	4.33	(0.64)	3	5	-0.42	-0.69
PK7	4.54	(0.56)	3	5	-0.68	-0.60
CK1	4.67	(0.51)	3	5	-1.11	0.06
CK3	4.77	(0.42)	4	5	-1.27	-0.39
CK4	4.39	(0.61)	2	5	-0.55	-0.14
CK5	4.56	(0.57)	3	5	-0.86	-0.26
CK6	4.15	(0.70)	2	5	-0.34	-0.54
TK1	4.33	(0.70)	2	5	-0.73	0.00
TK2	3.86	(0.93)	1	5	-0.48	-0.27
TK3	4.25	(0.72)	2	5	-0.58	-0.29
TK4	4.25	(0.70)	2	5	-0.68	0.29
TK5	3.88	(0.85)	1	5	-0.49	0.00
TK6	4.21	(0.79)	2	5	-0.81	0.22
TK7	4.04	(0.81)	2	5	-0.43	-0.51
PCK1	4.41	(0.59)	3	5	-0.39	-0.71
PCK3	4.47	(0.60)	3	5	-0.66	-0.52
PCK4	4.57	(0.55)	2	5	-0.95	0.55
PCK5	4.70	(0.46)	3	5	-0.99	-0.74
PCK6	4.64	(0.51)	3	5	-0.91	-0.49
TPK1	4.29	(0.65)	2	5	-0.43	-0.37
TPK2	4.29	(0.66)	2	5	-0.45	-0.42
TPK3	4.36	(0.66)	2	5	-0.62	-0.35
TCK1	4.13	(0.76)	2	5	-0.45	-0.48
TCK2	3.86	(0.79)	2	5	-0.02	-0.86
TCK3	3.88	(0.77)	2	5	-0.15	-0.57
TCK4	3.85	(0.82)	2	5	-0.08	-0.83
TCK5	4.18	(0.70)	3	5	-0.26	-0.96
TPACK1	4.20	(0.67)	2	5	-0.39	-0.28
TPACK2	4.33	(0.62)	2	5	-0.43	-0.21
TPACK3	4.27	(0.64)	2	5	-0.54	0.45
TPACK4	4.22	(0.67)	2	5	-0.42	-0.22
TPACK5	3.98	(0.82)	1	5	-0.47	-0.12

Legend: M – Mean; SD – Standard Deviation; Min – Minimum score; Max – Maximum score; Skew – Skewness coefficient; Kurt – Kurtosis coefficient

Appendix C: Items in the final five-factor model

PK	
PK1	I can adapt my teaching based upon what students currently understand or do not understand.
PK2	I can adapt my teaching style to different learners.
PK3	I can use a wide range of teaching approaches in a classroom setting.
PK4	I can assess student learning in multiple ways.
PK5	I know how to assess student performance in a classroom.
PK7	I know how to organize and maintain classroom management
PCK1	I know how to select effective teaching approaches to guide student thinking and learning in my teaching subject.
PCK3	I know how to develop exercises with which students can consolidate their knowledge of my teaching subject.
PCK4	I know how to evaluate students' performance in my teaching subject.
PCK6	In my teaching subject I can identify from student errors where there are difficulties in understanding and give appropriate feedback.
CK	
CK3	I know the basic theories and concepts of my teaching subject.
CK4	I know the history and development of important theories in my teaching subject.
CK5	I have various ways and strategies of developing my understanding of my teaching subject.
CK6	I am familiar with recent research in my teaching subject.
TK	
TK1	I keep up with important new technologies.
TK2	I frequently play around with the technology.
TK3	I know about a lot of different technologies.
TK4	I have the technical skills I need to use technology.
TK5	I know how to solve my own technical problems.
TK6	I can learn technology easily.
TK7	I have had sufficient opportunities to work with different technologies.
TCK	
TCK1	I know how technological developments have changed the field of my subject.
TCK2	I can explain which technologies have been used in research in my field.
TCK3	I know which new technologies are currently being developed in the field of my subject.
TCK4	I know how to use technologies to participate in scientific discourse in my field.
TCK5	I know technologies which help me understand my subject.
TPACK	
TPACK1	I can use strategies that combine content, technologies, and teaching approaches.
TPACK2	I can choose technologies that enhance the content for a lesson.
TPACK3	I can select technologies to use in my classroom that enhance what I teach, how I teach, and what students learn.
TPACK4	I can teach lessons that appropriately combine my teaching subject, technologies, and teaching approaches.

TPK1	I can choose technologies that enhance the teaching approaches for a lesson.
TPK2	I can choose technologies that enhance students' learning for a lesson.
TPK3	I can adapt the use of the technologies that I am learning about to different teaching activities.

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