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Research Article

Validating a TPACK Instrument in the Moroccan Context: A Four-Factor Model for Pre-service Mathematics and Sciences Teachers

Jamal Ahmichane[1*], **Abdellatif Jhilal**[2], **Youness Hadder**[2], **Mostafa El Mallahi**[1]

[1] Department of Mathematics and Computer Sciences, Ecole Normale Supérieure, Sidi Mohamed Ben Abdellah University, Fez, Morocco.
[2] Regional Center for Education and Training Professions (CRMEF) Fez-Meknes, Fez, Morocco.

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***Corresponding Author:** J. Ahmichane
✉ jamal.ahmichane@usmba.ac.ma

Abstract

Numerous theoretical frameworks have been proposed to guide research on teachers' technology integration. Among them, the Technological Pedagogical Content Knowledge (TPACK) framework has recently emerged as a prominent conceptual model, emphasizing the composite knowledge teachers require to integrate technology into teaching effectively. This study aims to investigate the development of TPACK among primary school pre-service teachers (PSTs) specializing in mathematics and science within the Moroccan context. 403 PSTs in postgraduate teacher preparation programs participated in this research and completed the TPACK survey. Their responses were analyzed using exploratory and confirmatory factor analyses (EFA and CFA). The survey instrument, consisting of 32 items, was categorized into five major subgroups corresponding to core TPACK components. Findings revealed that pre-service teachers faced difficulty distinguishing and self-reporting their technological pedagogical knowledge. The CFA results demonstrated that the constructs of TPACK, content knowledge, pedagogical knowledge, and technological knowledge were valid and reliable indicators of pre-service teachers' competencies in this setting, despite the relatively weak convergent validity observed in the pedagogical knowledge component. The study offers implications and recommendations for future research and teacher education practices. In particular, the validated TPACK survey provides a potential diagnostic tool for assessing novice teachers' knowledge profiles and identifying areas for professional growth. These insights enhance technology integration courses and strengthen teachers' instructional efficacy across North African educational contexts.

Keywords: Confirmatory Factor Analysis (CFA); Content Knowledge; Preservice Teacher; Primary School; Pedagogical Knowledge; Technological Knowledge.

1. INTRODUCTION

Personal computers are increasingly prevalent in classrooms across many developed nations; however, teachers' use of information and communication technology (ICT) remains under scrutiny. Research indicates that teachers tend to employ ICT only occasionally. When they do, it is mainly for transmitting information rather than supporting students in actively constructing knowledge [1]. These findings have prompted educators and policymakers to place stronger emphasis on preparing teachers to integrate ICT more effectively in their instructional practices. One of the most widely recognized approaches in this regard is the Technological Pedagogical Content Knowledge (TPACK) framework, which describes the complex body of knowledge required for teachers to teach subject matter with technology support successfully [2]. Building on Shulman's concept of pedagogical content knowledge, TPACK extends the framework by incorporating technological knowledge as a crucial dimension [3], [4].

A review of major bibliographic and citation databases, such as Scopus and Web of Science, shows that since 2011, more than 3,000 academic contributions, including journal articles, review papers, conference proceedings, and book chapters, have been published on the concept of "technological pedagogical content knowledge." Mishra and

Koehler [5] argue that effective ICT integration in teaching requires the combination of three essential domains: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). They further contend that the interplay among these domains generates four additional forms of integrated knowledge: technological content knowledge (TCK), technological pedagogical knowledge (TPK), pedagogical content knowledge (PCK), and the comprehensive construct of TPACK. These seven dimensions encapsulate the professional knowledge pre-service teachers (PSTs) must acquire to integrate technology meaningfully into their teaching practice.

Content knowledge refers to mastery of subject matter, such as mathematics, languages, or natural sciences. In contrast, pedagogical knowledge relates to understanding teaching and learning strategies that acknowledge the diversity of students' needs [6]. Technological knowledge, in turn, encompasses familiarity with the rapidly evolving landscape of digital technologies and their expanding functionalities [7]. When these three domains intersect, teachers develop more specialized professional knowledge. For instance, technological content knowledge enables them to understand how subject matter can be represented through technology, such as using animations to illustrate DNA replication. Pedagogical content knowledge equips teachers to design instructional approaches that make subject matter more comprehensible to students. In contrast, technological pedagogical knowledge concerns the ability to apply technology-based strategies within pedagogical contexts. The convergence of these three domains ultimately gives rise to TPACK, which represents the integrated knowledge necessary for teaching and learning with technology in pedagogically sound and content-appropriate ways [5].

Ong and Annamalai [8] emphasize that the TPACK framework provides a solid empirical foundation for developing ICT-related curricula. Extensive and validated survey instruments are required to measure teachers' progress in professional development programs [9]. Several questionnaires based on the TPACK model have been developed, yet large-scale exploratory and confirmatory factor analyses have often failed to capture all seven constructs initially identified distinctly [5]. This limitation highlights a critical research gap, particularly regarding refining measurement instruments and advancing factor-analytic studies on TPACK.

The TPACK of Arabic primary school PSTs across different subject domains is evaluated using relatively few tools. To address this limitation, the present study seeks to design and validate a self-report survey instrument tailored to assessing the TPACK of future teachers in Moroccan primary schools. Establishing the validity and reliability of such an instrument would provide valuable insights into the strengths, weaknesses, and areas requiring improvement within teacher education programs. As one of the first studies to focus exclusively on primary school PSTs preparing to teach mathematics and science, this research aims to contribute to filling a notable gap in the literature and to support the advancement of teacher professional development in the integration of ICT.

2. LITERATURE REVIEW

Recent calls for educational reform suggest that professionals in the field should begin preparing for fully integrated technology and focus more on students' content and process-related learning, rather than treating technology merely as a separate instructional tool [10]. Such integration is expected to create more effective teaching and learning environments. In line with this perspective, an increasing body of literature has emerged exploring various approaches and theoretical models for successfully integrating technology into instruction. One of the most influential frameworks for examining the intersection of content knowledge, pedagogy, and technology in teaching is the Technological Pedagogical Content Knowledge (TPACK) framework [11].

The TPACK framework builds upon Shulman's [12] The Pedagogical Content Knowledge (PCK) model emphasizes that mastering subject matter and pedagogical methods independently is insufficient. Shulman argued that an essential intersection between pedagogy and content PCK reflects teachers' capacity to understand subject matter and present it in ways that enhance student learning. This perspective highlights why many teachers struggle to teach effectively despite strong subject expertise when they cannot integrate pedagogical strategies with content delivery. Expanding on this model, Mishra and Koehler [5] concluded that technology must also be incorporated, giving rise to TPACK. They argued that technological knowledge, when effectively combined with content and pedagogical knowledge, can significantly enrich learning experiences. In addition, Mishra and Koehler underscored the importance of developing valid and reliable instruments to evaluate teachers' TPACK, a challenge that has inspired a wave of subsequent research [13]–[15].

The most widely used method for measuring teachers' TPACK has been the administration of self-report surveys. Review studies have shown that more than half of TPACK-related research relies on such instruments, where participants evaluate their confidence and practices using Likert-scale items. These surveys are typically structured into subscales representing the TPACK model's different domains. Among the most prominent instruments is The Survey of Pre-service Teachers' Knowledge of Teaching and Technology developed [9]. Designed specifically to capture pre-service teachers' (PSTs) perceptions of TPACK in primary schools, the instrument consists of 47 items across seven subscales, with subject-specific emphasis on social studies, science, mathematics, and literacy. Items include statements such as, "I can use a wide range of pedagogical approaches in class preparation" (PK) and "I continue to stay up to date on new and significant technologies" (TK). Empirical testing has confirmed the instrument's validity and reliability, making it a widely adopted tool for evaluating the development of PSTs' TPACK.

While some studies have adapted these instruments to different contexts, all remain fundamentally aligned with the TPACK framework. For example, Adipat [16] demonstrated that technology-enhanced content and language-integrated learning (T-CLIL) instruction significantly improved PSTs'

TPACK, as reflected in consistent score increases across all seven framework elements over four intervals. Other studies have modified the scale for specific subject domains. Zelkowski et al. [17], for instance, adapted Schmidt et al.'s instrument to evaluate TPACK among secondary mathematics PSTs. Their findings indicated that while CK, TK, PK, and TPACK could be reliably measured, domains such as TCK, TPK, and PCK remained more difficult for participants to distinguish. Their revised scale consisted of 22 items across the four more stable domains. Similarly, Marlina et al. [18] developed the "TPACK Biology Dimensions" instrument, which includes 44 items across eight domains for assessing biology PSTs' TPACK. In another example, Pondee et al. [19] employed the TPACK framework to restructure a pre-service science teacher education course using mobile game technology. They introduced a pedagogical module of Mobile Game-based Inquiry Learning in Science (MGILS) and measured improvements across TK, TCK, TPK, and TPACK, reporting significant incremental gains in PSTs' integration abilities.

Despite the growing number of instruments, most TPACK studies have been conducted in the United States, which has prompted increasing efforts to develop and adapt TPACK surveys in other languages and educational contexts. For example, Kartal and Çınar [20] created a TPACK survey for use in Turkey, while Ku et al. [21] developed the Teachers Maker-based TPACK Survey Instrument (TMTSI) in Taiwan, validated through confirmatory factor analysis as a reliable research instrument and a professional development tool. In the Arab region, H. E. Alharbi [22] designed an Arabic instrument with 27 items for 350 secondary PSTs. The survey, structured around seven factors corresponding to TPACK's conceptual domains, was validated through confirmatory factor analysis and deemed reliable for assessing PSTs' TPACK.

Nevertheless, research using TPACK self-reporting instruments remains limited in the Middle East and North Africa. For example, Alsuwaihel [23] examined how augmented reality competencies and English as a foreign language (EFL) TPACK components predicted the quality of EFL teaching among pre-service undergraduates in Saudi Arabia. Additionally, only two studies have investigated PSTs' perceptions of TPACK in Saudi Arabia: one used A. A. M. Alharbi's [24] survey, while the other employed a modified version of Sarıçoban et al.'s instrument [25].

These findings highlight that few studies have developed Arabic survey instruments explicitly tailored for assessing the TPACK of PSTs in primary schools across subject areas. The scarcity of such research is especially evident in the North African context. Given this gap, the present study aims to adapt and validate a survey instrument for use with PSTs learning to teach mathematics and science in Moroccan primary schools. By ensuring the reliability and validity of the instrument, the study seeks to provide valuable insights into PSTs' TPACK, thereby contributing to the enhancement of teacher education programs. Accordingly, the central research question guiding this study is: Can the TPACK instrument be validated as a reliable tool for assessing the TPACK of pre-service primary school teachers in the study context?

3. MATERIAL AND METHODS

3.1. Instrument Adaptation

The assessment of PSTs' TPACK in Moroccan primary schools was primarily conducted through the adaptation of a self-reported survey originally developed [26], complemented by an extensive review of the literature [9], [22], [27]. The adapted tool encompassed five TPACK components: pedagogical knowledge (PK), content knowledge (CK), technological knowledge (TK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK). In its preliminary stage, the instrument consisted of 32 items, which were categorized according to the definitions of the TPACK model and allocated to the appropriate subdomains.

Three faculty experts with backgrounds in teaching and educational technology across different subject areas reviewed the items' face and content validity to ensure clarity, accuracy, and relevance. Based on the feedback received, several modifications were implemented. Item 15 was removed and replaced with new items directly related to mathematics and science. In items 19, 25, and 27, the term "first teaching subject" was substituted with "mathematics," while in items 20, 26, and 28, the phrase "second teaching subject" was replaced with "science." Because social media is not commonly employed within the Moroccan educational system, items 13, 16, 17, and 18 were revised to exclude references to social media. Furthermore, two new items were added, "I have sufficient knowledge about science" and "I have sufficient knowledge about mathematics," to strengthen the instrument's alignment with the study's focus on mathematics and science teaching.

Table 1. Sample of the TPACK Survey Items.

Code	Items Description
PK	I can identify appropriate topics for group activities. I teach my students to monitor their own learning.
TK	I can teach my students to use technology tools. I have the technical skills I need to use technology.
TPACK	I can teach lessons that appropriately combine teaching mathematics, technologies and teaching approaches. I can teach lessons that appropriately combine teaching science, technologies and teaching approaches.
CK	I can think about mathematics like a subject matter expert. I have sufficient knowledge about science.
TPK	I am thinking critically about how to use technology in my classroom. I can adapt the use of technologies that I am learning about to different teaching activities.

As a result, the adapted instrument consisted of twelve items for pedagogical knowledge (PK), six for content knowledge (CK), five for technological knowledge (TK), six for technological pedagogical content knowledge (TPACK), and three for technological pedagogical knowledge (TPK). These components were essential for pre-service teachers (PSTs) to develop a comprehensive understanding of technology integration. A sample of the survey items in Table 1.

The instrument employed a five-point Likert scale to capture participants' responses. This scale was chosen because it offers a range of options that effectively measure the degree of knowledge across a continuum. The response categories included Strongly Agree (SA), Agree (A), Neither Agree nor Disagree (N), Disagree (D), and Strongly Disagree (SD). Scores ranged from five points for Strongly Agree to one for Strongly Disagree. Consequently, the overall score could vary between 32 and 160, with higher scores indicating a stronger level of TPACK knowledge.

3.2. Participants

The participants of this study were male and female primary school pre-service teachers (PSTs) enrolled in the teacher preparation program at the Regional Center for Education and Training Professions (CRMEF) in Fez, Morocco, and its affiliated annexes in surrounding cities. All participants had previously completed either a bachelor's or a master's degree across diverse academic disciplines, which qualified them for entry into the program. The total population was 537 students, each undertaking a 22-week semester devoted to a foundational ICT training program. From this cohort, 403 valid responses were collected, representing a robust response rate of 75%. This high level of participation provided a reliable sample for subsequent analyses and strengthened the generalizability of the study's findings.

3.3. Data Analysis

After importing the data, it was screened to ensure no missing. The database was then reviewed for outliers, such as correlations, which may significantly impact statistical analysis. In fact, a prerequisite for many statistical processes is the lack of outliers. For example, when a dataset includes outliers, the results could be inaccurate in some correlation coefficient-based analytical procedures [28], such as factor analysis. Standard ratings (z-scores) were produced and analyzed to find potential univariate outliers, with z-scores more than 3 indicating univariate outliers. Forty-one univariate outliers were discovered and eliminated. The Mahalanobis distance was then investigated to identify potential multivariate outliers. Applying the Mahalanobis distance's threshold value ($\chi^2(32) > 61.2$, $\rho < 0.001$), 10 multivariate outliers were detected and removed. Participation in filling out the form by PSTs was not via email; it was in person in thirteen classrooms. Therefore, some PSTs in each school were embarrassed to complete the form and did not want to participate in this research. This led to many aberrant and illogical cases (51 cases). Using the factor analysis test, identifying factors with good loading is possible while removing aberrant cases. This is not possible when some or all of these aberrant cases exist. As a result of these reductions, 352 cases were retained for factor analysis.

To evaluate the TPACK survey instrument in the Moroccan setting, both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were performed. EFA was employed with the principal axis factoring extraction method and direct rotation to examine each subscale's content validity. 32 items constitute the initial survey version that the study's sample completed. Based on items that were under-loading were eliminated, followed by removing items that were cross-loading. One by one, items were taken away. Only the under-loading item with the lowest loading was thus eliminated at each iteration of the EFA process. To reiterate, an item was considered under-loaded if its most significant correlation with any latent component was 0.4 or lower, according to Mirabelli et al. [29] item was said to be cross-loading when it loaded onto two factors; each factor had a correlational strength of 0.3 or greater. The second-highest item loadings were compared to ascertain the retention of cross-loading items. The cross-loading item that had the most significant factor loading among all the other cross-loading items was eliminated. In case eliminating an under-loading item led to a cross-loading of a subsequent item, the items were eliminated before removing any more under-loading items.

In addition to testing content validity using EFA, the researcher conducted construct validity analysis by examining the instrument's design and measurement accuracy for the fictitious TPACK domains. As a result, CFA was carried out, and a CFA model was constructed using EFA results and the TPACK theory as a foundation. Using maximum likelihood estimation, the variance–covariance matrix was analyzed. Several model fit parameters were evaluated to determine the optimal model fit. Table 2 presents the standard fit criteria for acceptable fit and excellent fit values, adapted from [30], [31].

Table 2. Standard Fit Criteria

Fit Statistics	Acceptable Fit (AF)	Excellent Fit (EF)
IFI	0.90–0.94	≥ 0.95
TLI	0.90–0.94	≥ 0.95
CFI	0.90–.95	≥ 0.97
GFI	0.90–.95	≥ 0.97
Chi-Square /df	≤ 5.00	≤ 3.00
RMSEA	0.06–0.08	≤ 0.05
AGFI	≥ 0.80	≥ 0.85

Then, the average variance extracted (AVE), the composite reliability (C.R.), and the Cronbach alpha (α) coefficient index were estimated to examine the validity and the reliability. Satisfactory construct reliability is indicated by α and C.R. values of 0.7 or higher, whereas an AVE of at least 0.5 indicates satisfactory construct validity.

3.4. Ethical Concerns

The instructors of PSTs gave their permission to participate. Then, PSTs received the survey's final version and a well-informed permission form during the scheduled lecture time. Once the PSTs had been informed of the purpose of the research, their voluntary participation in the survey was requested. They received guarantees of anonymity and confidentiality, with the understanding that their answers would only be used for the study. Direct transfers of permission forms and completed surveys were made to the researcher.

4. RESULTS

4.1. Populations' Characteristics

The study involved 403 male and female participants, as detailed in Section 3.3. Most participants were between 26 and 30 (78.20%), followed by those aged 20 to 25 (21.80%). Regarding academic qualifications, 36 pre-service teachers (8.90%) held a professional bachelor's degree in education science, while 7.9% had obtained a master's degree. Most participants (91.80%) had completed a bachelor's degree and were enrolled in a teacher preparation program. Their specialized instruction fields included mathematics, sciences, and French, while their bachelor's or master's specializations were distributed across arts (34.20%) and sciences (65.80%).

Additionally, 74.70% of the pre-service teachers possessed a certificate or diploma in computer science. Regarding professional experience, 354 participants had less than one year of experience, 41 had between one and four years, and only 8 had more than four years. Regarding computer proficiency, over 70% of the participants could operate a computer, connect it to other digital devices, and install or uninstall software programs.

4.2. Exploratory Factor Analysis (EFA)

EFA was used to examine the instrument's factor structure on the representative sample (n = 160). Cronbach's α = 0.773 indicated that the tool passed the reliability test. Instead of using eigenvalues, the number of components in the extraction was initially fixed at five [26]. EFA was carried out on the 32 items with the principal axis factoring extraction method and direct oblique rotation. The initial EFA on the data showed distinct factors only for TK, PK, CK, and TPACK (Table 3). The items written to measure TPK were removed during the EFA process, and three items of the PK component were isolated in factor 5. Therefore, we decided to eliminate the TPK elements from the analysis, and the number of components in the extraction was fixed at four.

The results showed that the data were acceptable for factor analysis, as demonstrated by the KMO value of 0.66 and the Bartlett's test of sphericity (BTS = 1442; p = 0.000). Consequently, four factors were produced by keeping 21 items and eliminating 11 items. These constructs contributed to 41.24% of the model's total variance. Table 4 shows the items' factor loadings. These findings revealed that the four-factor approach accurately described the TPACK questionnaire.

Table 3. Exploratory Factor Analysis (EFA) Five Factors Results

Items	Factors				
	1	2	3	4	5
TK3	0.681				
TK2	0.665				
TK4	0.657				
TK5	0.641				
TK1	0.473				
CK3		0.804			
CK4		0.784			
CK5		0.745			
CK6		0.577			
CK2		0.356			
PK5			0.566		
PK11			0.548		
PK8			0.513		
PK4			0.452		
PK6			0.434		
PK7			0.414		
TPACK2				-0.685	
TPACK1				-0.659	
TPACK4				-0.638	
TPACK3				-0.622	
PK12					0.599
PK9					0.550
PK10					0.265

Exploratory Factor Analysis (EFA) was employed to investigate the underlying factor structure of the adapted instrument using a representative subsample (n = 160). The scale demonstrated acceptable internal consistency, with a Cronbach's α of 0.773, confirming that the instrument met the threshold for reliability in educational research. Guided by Chai et al. [26] the initial extraction was set to five components. The analysis was performed on all 32 items using principal axis factoring with direct oblique rotation, a method well-suited for potentially correlated factors.

Table 4. Exploratory Factor Analysis (EFA) Four Factors Results

Items	Factors			
	1	2	3	4
TK2	0.746			
TK3	0.680			
TK5	0.618			
TK1	0.562			
TK4	0.546			
CK5		0.767		
CK3		0.761		
CK4		0.725		
CK6		0.602		
CK2		0.493		
CK1		0.436		
PK11			0.585	

Items	Factors			
	1	2	3	4
PK8			0.575	
PK5			0.564	
PK6			0.439	
PK7			0.422	
PK4			0.417	
TPACK4				-0.647
TPACK2				-0.621
TPACK3				-0.620
TPACK1				-0.568

The preliminary results indicated that distinct and interpretable factors emerged for technological knowledge (TK), pedagogical knowledge (PK), content knowledge (CK), and technological pedagogical content knowledge (TPACK) (Table 3). However, the items intended to measure technological pedagogical knowledge (TPK) did not exhibit strong or consistent loadings on a unique factor, suggesting conceptual overlap or item misalignment. Moreover, three PK items were isolated within a separate factor, further complicating the five-factor model. The TPK items were excluded in response, and the extraction model was re-specified to four components.

4.3. Confirmatory Factor Analysis (CFA)

The first CFA findings showed that the model fit was not very good; the χ^2 was 875.552, with df (183) and ρ-value < 0.001. A poor fit is shown by the ratio $\chi^2/df = 4.78$, higher than three (Table 2). The model's evaluation was expanded upon by contrasting it with additional fit indices (TLI = 0.74, CFI = 0.78, GFI = 0.82, IFI = 0.78, AGFI = 0.78, and RMSEA = 0.1). The comparison of these indices with the fit criteria in Table 2 indicated insufficient model fit. Thus, model improvement was recommended.

Table 5. Fit Values Obtained in the Improved Model (n = 352)

Fit Statistics	Fit value for the Model	Explanation
IFI	0.95	Excellent Fit
TLI	0.94	Acceptable Fit
CFI	0.95	Acceptable Fit
GFI	0.92	Acceptable Fit
Chi-Square /df	1.86	Excellent Fit
RMSEA	0.05	Excellent Fit
AGFI	0.90	Excellent Fit

Numerous evaluations of the impact of various modification indices were conducted to improve the model. The largest estimate was considered and accepted only when the elements shared the same factor and were reasonably related. For instance, the original model incorporates covariances between e9 and e10, e7 and e10, and e17 and e19. Additionally, when the CK1 item was eliminated from the CFA model, the AVE value of the CK factor increased from 0.45 to 0.5. After making these changes, a new model with new characteristics was produced, and the updated model showed a generally excellent fit (Table 5 and Figure 1).

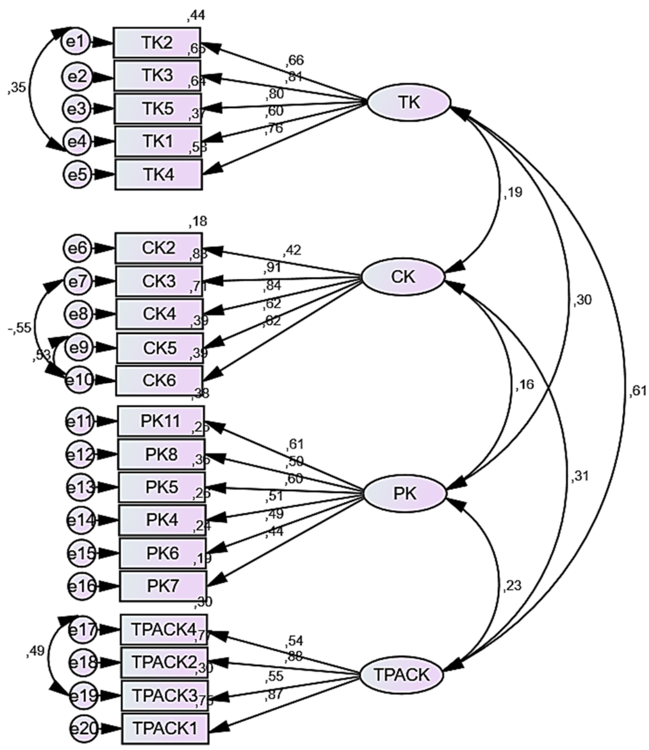

Figure 1. The Improved Model of CFA

4.4. Construct Validity and Reliability

The principles of validity and reliability of the developed instrument were established by examining the CFA results. As shown in Table 6, Cronbach's alpha (α) values ranged from 0.70 for PK to 0.85 for TK, while the computed composite reliability (C.R.) indices followed a similar range (0.70 for PK to 0.85 for TK). These results confirm satisfactory construct reliability for TK, CK, PK, and TPACK, as all measures exceeded the minimum threshold of 0.70. Convergent validity was further evaluated using the Average Variance Extracted (AVE), which reflects the proportion of variance in the indicators explained by the latent construct.

Table 6. Results of Validity and Reliability Tests

Constructs	Items	Factors Loading	AVE	α	C.R.
TK	TK2	0.665	0.53	0.85	0.85
	TK3	0.806			
	TK5	0.800			
	TK1	0.605			
	TK4	0.763			
CK	CK2	0.421	0.50	0.83	0.82
	CK3	0.909			
	CK4	0.840			
	CK5	0.622			
	CK6	0.624			
PK	PK11	0.613	0.28	0.7	0.70

Constructs	Items	Factors Loading	AVE	α	C.R.
	PK8	0.502			
	PK5	0.600			
	PK4	0.512			
	PK6	0.490			
	PK7	0.438			
TPACK	TPACK4	0.544	0.53	0.83	0.81
	TPACK2	0.880			
	TPACK3	0.546			
	TPACK1	0.866			

The factor loadings for the four dimensions (TPACK, CK, TK, and PK) ranged between 0.421 and 0.909, with AVE values falling within acceptable limits, except for PK, which recorded an AVE of 0.28. However, this was considered acceptable given that its α value reached 0.70. The findings demonstrated adequate convergent validity, as each item loaded appropriately on its respective factor. These results prove that the proposed instrument is valid and reliable for measuring the TPACK framework of Moroccan pre-service teachers in primary schools.

5. DISCUSSIONS

The literature review emphasizes how important it is to keep working to investigate and improve the potential applications of the TPACK model. It is thought that improving the TPACK model would make it possible to use it to help teachers get ready for integrating technology in the classroom. Upon reviewing the collection of literature, various methodological strategies for examining teachers' TPACK were discovered. Out of all the assessed methodologies, no validated North African survey instrument might be deployed to evaluate the TPACK of PSTs in primary schools across mathematics and sciences.

In this study, a self-reporting survey TPACK instrument was adapted and intended for PSTs in primary school in Morocco, more precisely in the teaching of mathematics and science disciplines. Its validity and reliability were examined with Arabic speakers. The factor analyses' results and reliability and validity indices made it possible to validate a generally reliable four-factor model (CK, TK, PK and TPACK). These results are consistent with those of those found to have inadequate convergent validity in some TPACK components [17], [26], [32]. In contrast, they were not in line with other research that showed sufficient convergent validity [21], [22], [33]. However, two significant aspects of the TPACK theoretical framework deserve further analysis in the Moroccan context: the empirical absence of the TPK factor in the factorial results and the low convergent validity of the PK factor.

The inability of this model to distinguish the TPK factor from the other factors in the validated factor structure poses a significant theoretical and practical constraint. In the Moroccan context, this gap could give rise to multiple interpretations; firstly, it indicates a still unclear or stabilized understanding of the articulation between pedagogy and technology among the PSTs participating in this study. This is in line with the findings of Qiu et al. [34] who showed that "the teachers could not distinguish the boundaries between TPK and technological content knowledge (TCK), and TPK and synthesized TPACK." Similarly, Niess [35] asserted that novice teachers, with less pedagogical competence, had more difficulty articulating content, pedagogy, and technology. In addition, the conceptual analysis carried out by Cox and Graham [36] highlighted the difficulty of differentiating TCK, TPK, and PCK components in practice. Secondly, the structure of vocational training programs in the Moroccan Regional Center for Education and Training Professions (CRMEF), while incorporating ICT training in a module separate from other modules, does not place sufficient emphasis on specific pedagogical strategies for integrating technologies into contextualized teaching scenarios tailored to subject content [37], [38]. Trainee teachers are introduced to digital tools (TK) (e.g., mastery of software, use of video projector) as well as general pedagogical approaches (PK). However, they do not receive sufficient and well-structured support on how to articulate the two dimensions in concrete and reflective teaching practices [39], [40]. Furthermore, the sometimes-limited access to digital resources at training establishments is a further obstacle [41], [42]. Taken together, these factors constitute an obstacle to the development of integrated TPK-type knowledge.

Another disturbing result concerns the low convergent validity of the PK factor (AVE = 0.28 < 0.5), despite marginally acceptable composite reliability (C.R. = 0.7) [43]. This result suggests that, while the items are relatively consistent with each other, they explain only a small proportion of the PK factor relative to the measurement error. One explanation lies in the sometimes theoretically dense or abstract formulation of certain items for PSTs without consolidated pedagogical experience [44]. For example, the item "I can plan group activities for my students" presupposes advanced pedagogical reflexivity and assesses, among other things, pedagogical planning skills focused on collaborative learning. For PSTs, these skills are generally acquired after several years of practice [45] are likely to be subject to heterogeneous interpretations, contributing to a vague or variable understanding of the items and weakening the PK factor's convergent validity. This constraint supports the findings of Cox & Graham [36] regarding the challenge of PK isolation, especially for PSTs. In CRMEFs, pedagogy is frequently taught as a decontextualized theoretical corpus and artificially divided into discrete competencies (classroom management, planning, assessment). This limits the potential to develop an integrated vision of pedagogy [37]. It also reflects the structural challenges that these frameworks present.

In our sample, the high response rate for the upper categories of the Likert scale (76.05% for scores 4 and 5, with a ceiling effect at 32.81% for the maximum score) suggests a marked tendency toward agreement or positive self-assessment. This profile reflects a strong influence of social desirability, i.e., the tendency of respondents to provide answers that are acceptable or in line with social or institutional expectations [46]. This phenomenon is particularly plausible in a professional training context such as CRMEF, where PSTs seek to legitimize their professional status

[45] and the questionnaires focus on expected educational content or practices. These biases compromise the data's validity and limit the instruments' discriminatory power. Furthermore, this high proportion of self-assessed responses in high categories shows that the exclusive use of self-assessments is insufficient to measure complex knowledge such as TPK or PK, and calls for mixed approaches for a more reliable assessment.

The validation of the TPACK scale, specifically adapted to teaching mathematics and science among PSTs in Moroccan primary schools, has significant implications for several aspects of educational practice and policy. It provides a diagnostic tool for assessing their knowledge and identifying areas requiring reinforcement. As revealed by this study, the PK factor's poor validity and the absence of the TPK factor underline the urgent need to rethink how teacher training handles the TPK component. It is not simply a question of reinforcing the integration of technologies but of developing specific modules targeting explicitly TPK skills through contextualized learning situations, analysis of practices, and the design of teaching scenarios adapted to disciplinary content and integrating the digital tools [47]. Point out that active teaching approaches centered on reflective sequence design (teacher – design - capacity) are effective in developing real integration of TPK. For PK, the results suggest that better structuring around concrete professional skills (heterogeneity management, differentiated pedagogy, formative assessment, etc.) could help reinforce this factor's coherence in the PSTs' representations. It is essential to support future teachers in conceptualizing pedagogy not as a fixed theoretical corpus, but as a set of interconnected skills capable of adapting and responding to learners' cognitive and cultural heterogeneity [48], [49]. In addition, closer coordination between university training, CRMEFs, field tutors, and PSTs could foster the emergence of more integrated and contextualized professional knowledge. Finally, the results of this study can also guide program designers and educational decision-makers in their reflections on curriculum design and teaching strategies aimed at improving TPACK integration courses and ensuring that these are tailored to the specific needs of the Moroccan educational landscape.

6. CONCLUSION

Although the Arabic TPACK questionnaire validated in this study is considered an effective and essential tool for reducing the technological gap in educational fields in the Arab world, the study has certain limitations. The study sample was drawn from a single region of Morocco; therefore, the applicability of the results may be restricted to a particular demographic. Expanding the study to a larger and more diverse sample from several regions of Morocco and other North African countries would significantly contribute to the generalizability and comprehensiveness of the results. Methodologically, the low validity of the PK factor remains another vital limitation, raising questions about the conceptual and linguistic accuracy of certain items to make them more suitable for the Moroccan educational context.

Future studies focusing on the revision and contextual adaptation of TPACK factor items and the addition of an additional component on contextual knowledge (XK) to this tool will ensure the conceptual robustness and practical usefulness of the future TPACK assessment tool in the Moroccan educational context [50], [51]. Since the study relies on self-reported data, another limitation is the lack of a particular social desirability measure, like the Marlowe-Crowne scale [46]. Future studies should combine these self-reports with additional TPACK measures, including performance evaluations or classroom observations, and a social desirability measure to reduce potential biases. This could also provide substantial evidence of the convergent validity of self-reported TPACK. Furthermore, this instrument's absence of artificial intelligence (AI) items can be considered a study limitation in light of swift technological developments. Therefore, adding AI-related items to the TPACK scale would contribute to a more comprehensive view and strengthen its relevance and applicability to the current educational landscape [52]. Finally, this study included only PSTs in Moroccan primary schools. To determine whether the results of this study apply to other contexts, it is recommended that variations in the validation of the TPACK survey in Arabic between PSTs and in-service teachers in primary schools be studied.

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