JTET

JOURNAL OF TECHNICAL EDUCATION AND TRAINING
ISSN: 2229-8932 e-ISSN: 2600-7932

Vol. 18 No. 2 (2026) 179-192
https://publisher.uthm.edu.my/ojs/index.php/jtet

Structural Relationships in TVET Teachers' ICT Competencies: Professional, Pedagogic, and Student Development Dimensions

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DOI: https://doi.org/10.30880/jtet.2026.18.02.013

Article Info

Received: 17th June 2026
Accepted: 21st September 2026
Available online: 6th October 2026

Keywords

Undergraduate level TVET, TVET teachers, ICT competencies, PLS-SEM

Abstract

Major developed countries have actively prioritized the enhancement of Technical and Vocational Education and Training (TVET) educators' digital competencies, recognizing that fostering an digitally skilled teaching workforce is paramount to systematically closing the broader digital talent gap. As a global leader in the digital economy, China also focuses on establishing digital infrastructure, resource platforms, and ICT competencies among educators. Despite existing frameworks, their interpretation remains theoretically incomplete and difficult to visualize. Therefore, by applying PLS-SEM, this study aims to establish a systematic ICT Competency Framework to meet the developmental needs of undergraduate TVET (UTVET) teachers. The hierarchy of the ICT Competency model was tested, involving Teachers' Professional Competencies, Teachers' Pedagogical Competencies, and Students' Development Competencies using a validated instrument survey via a cluster sampling technique across 400 undergraduate-level TVET teachers as respondents in Guangdong Province, China. Teachers' Professional Competencies significantly predict Teachers' Pedagogical Competencies ($\beta = 0.914$, $p < 0.05$), indicating that professional ICT competencies are a key prerequisite for pedagogical implementation. Likewise, Teachers' Pedagogical Competencies also strongly influence Students' Development Competencies ($\beta = 0.605$, $p < 0.05$) compared to the influence of Teachers' Professional Competencies on Students' Development Competencies ($\beta = 0.307$, $p < 0.05$). In short, the findings support a good structure in developing professional competencies, which strongly affect student outcomes primarily through pedagogical competencies. This study provides empirical evidence of developing an ICT Competency Framework for UTVET teachers in Guangdong Province, China.

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1. Introduction

The international labor market is pursuing a profound structural transformation, alongside the increased breakthrough of information and communication technology (ICT) in various sectors of the global economy (World Bank, 2023). This revolution has not only contributed to reshaping the traditional education models but also intensified the demand for high-skilled digital talent (Karwa, 2025), with projections of global spending in digital transformation amounting to $3.9 trillion by 2027 (Sherif, 2024). Despite the profound future in the global economy, The Future of Jobs Report 2025 reveals that by 2030, 59% of the global workforce will face systemic challenges, where upskilling and reskilling are vastly needed in ICT to keep up with the ever-changing ICT technology breakthrough (World Economic Forum, 2025). In response to such concern, developed countries such as Germany, Japan, and the United States have reached a broad consensus in enhancing the digital responsiveness of Technical and Vocational Education and Training (TVET), focusing on undergraduate TVET level, which is essential for bridging the digital talent gap (Adnan et al., 2025; Chen et al., 2023; Kovalchuk et al., 2022).

In Asia, as the global leader in the digital economy sector, China has demonstrated strong competitiveness in digital trade, digital capital, and industrial digitalization. They have reached a total spending of 59.2 trillion yuan in 2024 in the digital sector, accounting for 43.8% of the national gross domestic product (GDP; China Academy of Information and Communications Technology, 2026; United Nations Conference on Trade and Development, 2025). Despite the high investment in the digital economy, the gap between digital economy talent supply and demand has intensified, with a record of 32 million digital economy talent shortage reported in late 2024 (China Academy of Information and Communications Technology, 2026). Focusing on the TVET sector, China has aggressively expanded its TVET institutions to undergraduate levels since 2019, where these institutions have rapidly established digital infrastructure and resource platforms. With the increasing digital economy and the issue of digital economy talent gap, and aligned with national policy directives, the focus for educational quality improvement has shifted from "hardware investment" to a more critical factor, i.e., ICT competencies for undergraduate TVET (UTVET) teachers (Huang, 2023; Ministry of Education of the People's Republic of China, 2025).

1.1 Critical Challenges and Conceptual Mismatches in Educator Competencies

Despite its strategic importance, the ICT Competency of UTVET teachers in China exhibits notable systemic weaknesses. Research indicates a severe "decoupling" issue between learner-centered pedagogical philosophies and actual classroom execution (Ali et al., 2021; Li, 2024b; Xie, 2024). According to Zamri et al. (2023), improving curriculum quality requires institutions to balance their core, compulsory, and specialized engineering subjects while actively cultivating generic soft skills and elements of humanity within lessons. Additionally, encouraging the use of digital tools for instruction and introducing entrepreneurship courses are highlighted as essential steps for modernizing the educational experience. This modernization is increasingly driven by emerging technologies like augmented reality (AR), which has seen significant research growth due to its ability to help students overcome visualization difficulties in complex technical subjects (Ali et a., 2021). As highlighted in recent literature,, many UTVET teachers experience technological fatigue and a lack of lifelong learning commitment—typically identified by low technology adoption, continuous training burnout, and passive engagement—often participating in technical training, academic discussions, and industrial exchanges in a superficial or compliance-driven manner (Liu & Cao, 2024; Tang & You, 2024). This engagement frequently persists as a hindrance in achieving a sustainable work-life balance within a fast-paced digital economy, where educators are constantly pushed to work faster to keep pace with the mounting workloads (Omar et al., 2018). Such an imbalance often leads to a decline in professional well-being and productivity, as the time management challenges inherent in modern busy schedules leave little room for deep, reflective practice necessary to internalize complex ICT competencies. The failure to internalize modern humanistic education concepts has led to insufficient understanding of digital ethics, which overemphasizes the instrumental use of technology at the expense of students' professional development (Wang & Chen, 2023; Xi et al., 2023). In real-world practice, most UTVET teachers find integrating ICT tools into the vocational context of teaching and learning a formidable challenge, resulting in a mismatch between the instructional content to be delivered and authentic industrial requirements that should be attained by the students (Kang, 2023; Yao & Zuo, 2023). For instance, recent surveys reveal that up to 68% of engineering and technical instructors lack recent industry collaboration and practical workflow experience, while over 54% experience difficulty with advanced industrial software tools (Zhang, 2024). Graduates frequently struggle to translate basic software menu operations into the complex, constraint-heavy digital workflows required in modern smart manufacturing (Gharaie, 2024; Pacher et al., 2024). This gap is often a result of the lack of contextual knowledge, implying the ability to apply technical software skills within the specific constraints and workflows of practicing engineers (Adnan et al., 2013, 2014). Meanwhile, at the institutional level perspective, ambiguous strategic policies from educational authorities and underdeveloped mechanisms of digital teaching and learning in TVET sectors hinder the digital transformation process (Meng &

Zhang, 2022; Zhao, 2022). Furthermore, a lack of digital collaboration either within the teaching force or the industries also hampers interdisciplinary innovation (Yao, 2024; Yi & Xue, 2022).

These are one of the fundamental obstacles from the lack of consensus related to the definition and scope of ICT Competencies. Even though China has developed mainstream educational frameworks such as the EU's Digital Competence Framework for Educators (DigCompEdu), UNESCO's ICT Competency Framework for Teachers (ICT CFT), and China's Digital Literacy of Teachers, these frameworks are largely rooted in traditional academic teaching philosophies. They exhibit a significant gap with the workshop-based TVET educational system, failing to accommodate the UTVET educational system as a whole to support the digital economy. Domestic academic inquiries are also struggling to accommodate comprehensive guidance for UTVET teachers, due to an underestimated view of learner autonomy as well as research bias in the same context (Guo, 2023; Li, 2024; Zhou, 2023). With these issues and concerns in hand, this study aims to establish a structured ICT Competency Framework to meet the development of digital economy talent needed by UTVET teachers and fill the existing research gaps.

1.2 Theoretical and Conceptual Framework

ICT competencies for educators are defined as a comprehensive set of knowledge, skills, and attitudes that enable teachers to utilize ICT tools confidently, critically, and responsibly to optimize and transform educational activities (Fernández-Batanero et al., 2022; Tinmaz et al., 2022). Focusing specifically on key functional domains in TVET, these competencies encompass technical operation for UTVET teachers, integrating pedagogical expertise as well as technological proficiency, which are operationally measured through validated survey items. The theoretical foundation constructed in this study is based on three complementary perspectives, as illustrated in Figure 1, namely Connectivism, the Technology Acceptance Model (TAM), and the Technological Pedagogical Content Knowledge (TPACK). In the context of UTVET teachers, teachers represent the nodes in the knowledge network, where they are expected to navigate the process of evolving industrial demands, construct personal networks, and maintain the digital environment during the process of teaching and learning. These are essential to cultivate students and prepare them to become new independent nodes. This is the main motion of connectivism, which emphasizes the nature of knowledge, together with the pivotal role of digital connectivity in TVET learning environments, in this study (Duke et al., 2013). Meanwhile, in the context of digitalization of UTVET teachers, TAM clarifies how teachers' attitude and beliefs influence their willingness to integrate ICT tools in teaching and learning. This theory classifies the adoption of technology in the educational context of this study, which is determined by Perceived Usefulness (PU) and Perceived Ease of Use (PEOU; Davis, 1989), ensuring that the framework developed in this study takes into account the human cognitive factors. Apart from these two theories, TPACK suggests that technology integration in meaningful learning arises with the combination of Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK), where such integration is context-dependent and acts as a structural basis for understanding the knowledge integration required for effective teaching and learning in TVET settings (Mishra & Koehler, 2006). All these aligned well with the specific context of UTVET teachers' ICT competencies, where content diversity and practical skills are deeply rooted simultaneously in classroom settings.

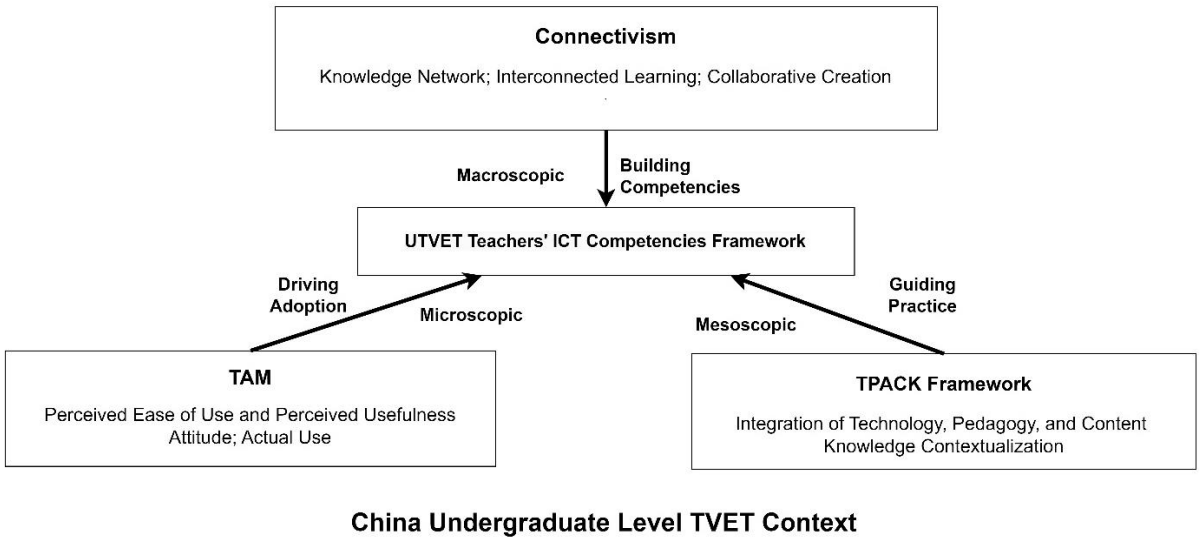


Fig. 1 *Theoretical framework of the study*

This study translated UTVET teachers' ICT competencies into eight operational key dimensions (A–H), as shown in Figure 2. These dimensions are further classified into three overarching areas to enhance the clarity and practical relevance of the proposed framework. The first area, Teachers' Professional Competencies, focuses on the foundational competencies of UTVET teachers to utilize ICT tools in order to enhance personal knowledge networks as the key nodes. This area is interconnected with Digital Awareness and ICT Knowledge & Skills, which fall directly under PU and PEOU in TAM. Collectively, it comprises the essential practical foundation for all activities related to ICT in teaching and learning. Meanwhile, the Digital Society Construction represents the ethical responsibility of UTVET teachers in maintaining and safeguarding the digital network environment in their capacity as key nodes. Simultaneously, the Digital Career Development and Digital Communication & Collaboration areas illustrate the core mechanisms needed by UTVET teachers to sustain their digital skills, representing the developmental principles in the TPACK framework.

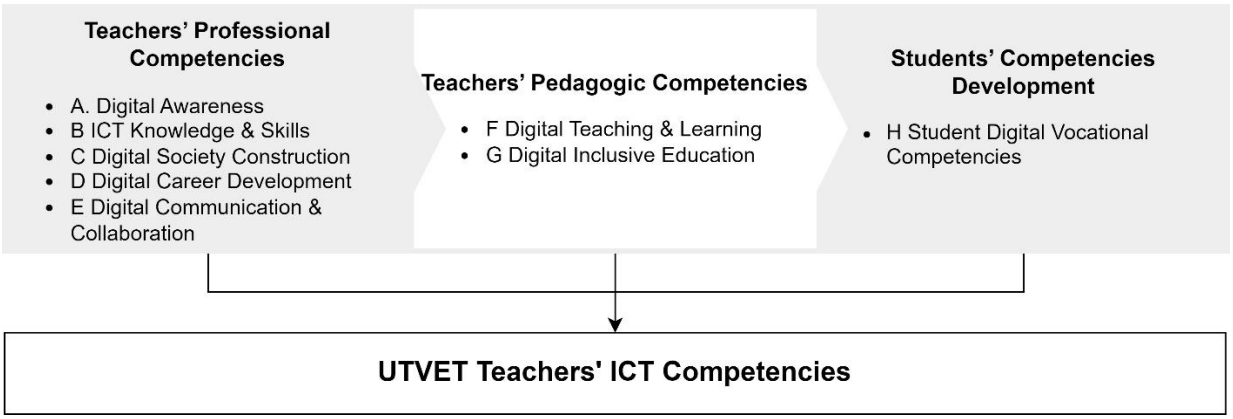


Fig. 2 *Conceptual framework of the study*

Subsequently, the Teachers' Pedagogical Competencies area, which emphasizes the practical integration of CK, PK, and TK, reflects the core behavioral application of technology among UTVET teachers. This area includes Digital Teaching and Learning, where the five-step (comprising Activity Design, Resource Development, Resource Utilization, Activity Management, and Assessment) instructional process to enhance the technology learning environment is outlined, and Digital Inclusive Education, both aligning with the emphasis of the contextual TPACK framework. The final area is the Students' Development Competencies area, which represents the ultimate goal of utilizing ICT tools in teaching and learning, where UTVET teachers empower students to become independent nodes in the framework developed in this study. Finally, the core and only dimension, Student Digital Vocational Competencies, emphasizes the teacher's role in enhancing technology acceptance, enabling students to use ICT tools creatively and responsibly for information acquisition, content creation, and problem-solving in a digitalized workforce.

2. Methodology

2.1 Research Design and Sampling

Quantitative research approach was adopted by utilizing a structured and validated instrument survey administered to UTVET teachers in Guangdong Province, China. Guangdong Province serves as the leading region in the digital economy (characterized by its dominant digital GDP scale, rapid industrial digitalization, and extensive digital TVET pilot initiatives) and acts as the pioneer region in transforming the undergraduate TVET landscape in China, providing a high degree of representativeness and generalizability (Tang & You, 2024; Zhou, 2021). A total of 2,759 UTVET teachers across 4 specialized institutions (Ministry of Education of the People's Republic of China, 2023b) were selected as the population in this study. By employing the cluster random sampling technique among each institution as the natural cluster and using G*Power analysis (linear multiple regression, effect size = 0.15, statistical power = 0.95), the minimum sample size determined was 260. To balance resource efficiency with geographic coverage, the target sample size was set at 350 to ensure sufficient statistical power. A total of 400 valid responses were obtained through a hybrid online and offline distribution of the survey, implemented fully anonymously with standardized instructions to ensure independent completion. Demographic profile of the respondents indicated that they were predominantly highly educated, ranging from young to middle-aged UTVET teachers, with career spans from early to mid-stage teaching careers in undergraduate TVET institutions.

2.2 Instrument Validation and Verification

The initial study started with an in-depth interview with TVET experts from well-known TVET institutions in Guangdong Province, China. From the thematic analysis of the interview conducted using the modified Delphi method, the instrument was developed and was then validated through consensus, up to three rounds of expert consultation (involving 10 Chinese experts: 6 educational technology specialists and 4 UTVET teachers), and cross-national validation (engaging 2 Malaysian experts). A pilot study was conducted involving 48 UTVET teachers in Guangdong Province, and Rasch analysis was employed to verify the instrument developed across critical psychometric properties, including reliability, item separation, item difficulty, point correlation, unidimensionality, category analysis, Differential Item Functioning (DIF), and fit statistics. The initial 125 items were assessed based on these parameters; specifically, 35 items were excluded due to non-compliance with fit criteria (Infit/Outfit MNSQ outside 0.5–1.5; |ZSTD| > 2) or redundancy, while maintaining at least three items per dimension to ensure structural integrity.. As a result, a 90-item self-assessment scale was developed to evaluate UTVET teachers' ICT competencies used in this study. The instrument employed a five-point Likert scale and demonstrated exceptional measurement robustness and internal consistency, evidenced by a Cronbach's alpha (α), indicating excellent internal consistency (Cronbach's α = 0.998).

2.3 Data Analysis

Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed in this study as the primary analytical technique due to its suitability for theory development in exploratory research, especially in its ability to effectively explain the variance of dependent variables without requiring a strict normal distribution of data (Hair et al., 2022). Following the preliminary data screening, the analysis was commenced in two stages, using SmartPLS 4.1.0.8 and IBM SPSS Statistics 29.0. The first stage started with the assessment of the outer model, also known as the measurement model, followed by the structural model, also known as the inner model, for the second-order constructs. The outer model assessment included internal consistency reliability (Cronbach's Alpha, Dijkstra-Henseler's rho_A and Composite Reliability ≥0.7), convergent validity (Average Variance Extracted ＞0.5), verifying indicator reliability (Factor loadings≥0.7) and also discriminate validity (Cross-loadings > Any other constructs' cross-loadings, Square of Constructs Correlation Coefficients < Average Variance Extracted and Variance Inflation Factor < 5) to ensure all observable variables reflect their respective latent variables accurately. Meanwhile, the inner model evaluation revolved around the strength, direction, and significance of the hypothesized paths to determine the relationships among latent variables involved in this study. A hierarchical component model (HCM) approach was subsequently adopted to sequentially construct and validate the third- and fourth-order models. Bootstrapping with 5,000 resamples was utilized in this study to enhance the reliability of statistical conclusions. This rigorous analytical approach allows for a comprehensive exploration of the structural relationships between the three main areas: Teachers' Professional, Teachers' Pedagogical, and Students' Development in UTVET teachers' ICT competencies. The non-parametric procedure was adopted to assess the stability of model estimates and accounts for the complex relationship among latent variables, while at the same time minimizing the impact of measurement error in the analysis (Anthonysamy et al., 2024).

3. Findings and Discussion

Preliminary data screening was conducted prior to the formal analysis to ensure the integrity and quality of the dataset. The first one involved the measurement of the Kaiser-Meyer-Olkin (KMO), which was reported above the recommend threshold of 0.60. Secondly, Bartlett's Test of Sphericity reached a statistical significance ($p < 0.05$), representing an adequate sampling suitability for factor analysis. Lastly, the Shapiro–Wilk test indicated that the data significantly deviated from normality ($p < 0.05$), where PLS-SEM is robust enough to violations of normality assumptions, hence confirming that the dataset is suitable for SEM.

3.1 Second-Order Model Analysis

Eight second-order models were initially specified and estimated in this study, where each model followed a consistent hierarchical component structure. The overarching latent variables (ICT competency dimensions A–H) were operationalized through 30 sub-competencies (A1–H6) as reflective measurement constructs, where observed indicators (Q9–Q98) manifest the underlying latent traits (Hair et al., 2022).

Table 1 presents the measurement model results for the eight second-order models. All factor loadings for the 90 indicators exceeded the recommended threshold of 0.7, indicating a strong indicator reliability. Likewise, all sub-competencies, Cronbach's α, and composite reliability exceeded the 0.7 threshold, indicating strong internal consistency reliability without excessive redundancy. The constructs also demonstrated satisfactory convergent validity with average variance extracted (AVE) values exceeding 0.5, indicating that the observed indicators explained a substantial proportion of variance. Furthermore, all variance inflation factor (VIF) values

were below the conservative threshold of 5, and all sub-competencies met the Fornell–Larcker criterion and cross-loading criteria, confirming the absence of multicollinearity and establishing satisfactory discriminant validity.

Table 1 *Measurement results of the second-order models*

Model	Dimensions	Results
Measurement Model (Outer Model)	Indicators Reliability	Factor loadings≥0.7
	Internal Consistency Reliability	Cronbach's Alpha (α)≥0.7
		Dijkstra-Henseler's rho_A (rho_A)≥0.7
		Composite Reliability (CR)≥0.7
	Convergence Validity	Average Variance Extracted (AVE)＞0.5
	Discriminate Validity	Cross-loadings＞Any other constructs' cross-loadings
		Square of Constructs Correlation Coefficients＜AVE
		Variance Inflation Factor (VIF)＜5
Structural Model (Inner Model)	Model Validity	0.845＜Path Coefficients (β) ＜0.943
		0.844＜Mean Path Coefficients (MB) ＜0.943
		t-values (t)>1.96
		p-values (p)<0.05
		Lower Confidence Interval, 2.5% (LCI) >0
		Upper Confidence Interval, 97.5% (UCI) >0
		0.714＜Coefficient of Determination (R2) ＜0.89
		Effect Size （f^2）>0.35

Evaluation of the structural model revealed that all path coefficients for the sub-competencies were ≥ 0.845, indicating strong positive relationships. The mean path coefficients (MB) showed no significant deviation from the original path coefficients, with t > 1.96 and p < 0.05, and confidence intervals excluding zero. This evidence supports the statistical significance of the relationships between ICT competencies (A–H) and their sub-competencies. Additionally, R^2 values reached approximately 0.75 and f^2 values significantly exceeded 0.35, indicating substantial explanatory power of the model where sub-competencies exert a large impact on ICT competencies, explaining 71.4% of the variance in the endogenous constructs, with the remaining 28.6% representing residual variance attributable to unmeasured contextual and individual factors.

3.2 Third-Order Model Analysis

Building upon the second-order results, three third-order models were developed. To ensure computational precision, the 90 observed variables were aggregated using mean scores to form 30 composite indicators (A1–H6). Subsequently, new structural models were specified, with Teachers' Professional Competencies, Teachers' Pedagogical Competencies, and Students' Development Competencies areas as the primary latent variables.

The assessment of the structural models confirmed that all measurement models demonstrated satisfactory indicator reliability, internal consistency reliability, convergent validity, and discriminant validity, with no multicollinearity issues. The inner model results were equally robust, with path coefficients exceeding 0.891. The MB showed no significant deviation from the original path coefficients, with t > 1.96 and p < 0.05, and the confidence intervals did not include zero. This demonstrates that the ICT competencies (A–H) are strongly and significantly associated with their respective overarching areas. Furthermore, R^2 ranged from 0.794 to 0.955, and f^2 values far exceeded 0.35, indicating that the ICT competencies explain 79.4% to 95.5% of the variance in the third-order constructs, representing a large impact.

3.3 Fourth-Order Model Analysis

Following the validation of the lower-order structures, a comprehensive fourth-order hierarchical model of UTVET teachers' ICT competencies was constructed to perform higher-order path analysis (Fig. 3). While Teachers' Professional Competencies did not yield an independent R^2 due to the absorption effect, the R^2 values for Teachers' Pedagogical Competencies and Students' Development Competencies areas were 0.834 and 0.799, respectively, while the overall ICT competencies construct reached an R^2 of 0.999. This indicates that the model

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accounts for 83.4% of the variance in teachers' pedagogical application and 79.9% of the variance in student development. Furthermore, the overall ICT competencies construct reached an R^2 of 0.999, confirming that the three lower-order domains virtually capture the complete conceptual spectrum of the framework, reflecting substantial explanatory power (Hair et al., 2022).

Table 2 *Measurement results of the fourth-order model*

Path	β	MB	SD	t	p	LCI (2.5%)	UCI (97.5%)	f2
TPROC -> TPEDC	0.914	0.913	0.011	79.64	0.000	0.889	0.934	5.052
TPROC -> SCD	0.307	0.309	0.06	5.084	0.000	0.191	0.431	0.078
TPEDC -> SCD	0.605	0.603	0.061	9.928	0.000	0.479	0.718	0.303
TPROC -> ICT competencies	0.529	0.529	0.008	68.519	0.000	0.514	0.544	13256.715
TPEDC -> ICT competencies	0.288	0.288	0.005	55.911	0.000	0.278	0.298	3242.761
SCD -> ICT competencies	0.219	0.219	0.005	41.572	0.000	0.209	0.23	2948.412

*TPROC – Teachers' Professional Competencies, TPEDC – Teachers' Pedagogical Competencies, SDC – Students' Development Competencies

All path coefficients were statistically significant ($t > 1.96$, $p < 0.05$), as shown in Table 2. It is evident that the Teachers' Professional Competencies area exerted a strong direct predictive effect on the Teachers' Pedagogical Competencies area ($\beta = 0.914$). These findings support the theoretical synergy between the underpinning theories of this study: Connectivism, TAM, and TPACK within the undergraduate TVET context, where teachers' digital awareness and ICT knowledge and skills act as the psychological mechanism representing the PU and PEOU. Even without this foundation, the subsequent pedagogical integration of TPACK becomes superficial. The substantial f^2 value ($5.052 > 0.35$) indicates that the Teachers' Professional Competencies area is a prerequisite for qualitative improvement in the Teachers' Pedagogical Competencies area. UTVET teachers are required to internalize the distributed knowledge mindset of Connectivism, to develop the capacity of constructing Personal Knowledge Networks, hence maintain their role as the key nodes in the knowledge network. Consequently, this provides a meaningful integration and strong foundation of ICT tools in TVET learning environments through the TPACK framework in the Teachers' Pedagogical Competencies area. Teachers' Pedagogical Competencies emerged as the strongest predictor of the Students' Development Competencies area ($\beta = 0.605$, $f^2 = 0.303 > 0.15$), with an impact nearly double that of the direct path from Teachers' Professional Competencies area to the Students' Development Competencies area ($\beta = 0.307$, $f^2 = 0.078 > 0.02$). This finding underscores that the mere possession of digital skills is insufficient. Instead, implementing immersive technology-enhanced blended learning models effectively fosters students' higher-order digital competencies across six essential dimensions: digital learning and reflection, digital skills and creation, digital communication and collaboration, digital responsibility and security, digital problem-solving thinking, and digital organization and entrepreneurship (Mahande et al., 2025; Ogwo, 2026).

Furthermore, these digital learning environments are instrumental in enhancing students' visualization skills, providing a critical bridge for learners to conceptualize complex technical structures and industrial workflows that are often difficult to grasp through traditional 2D materials (Ahmad et al., 2025).

This result highlights the need for critical transformation of logics, where a teacher's status as a central node does not automatically empower students directly. If teachers' ICT competencies remain at the professional level without being translated into pedagogical action, knowledge transmitted will remain stagnant without further impact on students' development. The Teachers' Pedagogical Competencies area represents more than a mere application of technology in TVET settings; it also embodies the art of connectivity. This is exemplified by the integration of mobile-based AR, which has been shown to enhance student engagement and performance by transforming abstract theoretical concepts into interactive, three-dimensional learning experiences (Ali et al., 2023). UTVET teachers must leverage the TPACK framework to fulfil the role of learning facilitators, delivering meaningful learning. For instance, UTVET teachers should practice using digital platforms to facilitate collaboration and guide students when trying to resolve authentic industrial problems within virtual simulations. The efficacy of the Teachers' Pedagogical Competencies area is the determining factor that can largely influence student transition from passive recipients of knowledge into independent nodes, who can contribute autonomously within the digitalized environment. Simultaneously, the Teachers' Pedagogical Competencies and Students' Development Competencies areas serve as the practical output and also the ultimate objective of the competency model, with path coefficients of 0.288 and 0.219, respectively. The relatively narrow margin between these values suggests that both domains play indispensable and complementary roles in the UTVET teachers' ICT

Competency Framework. Together, they facilitate the revolution of UTVET teachers from merely possessing technology to applying technology in TVET teaching and learning settings, transitioning from knowledge storage to node activation of facilitating an active learning environment utilizing technology. The framework successfully integrates educational transformation from the perspective of teachers' professional context, pedagogical practice, and student development. Consequently, the key node identity (rooted in Connectivism) and the intrinsic technology acceptance (rooted in TAM) as the "fundamental base" of the overall framework were constructed. Without this support, the holistic ICT Competencies of UTVET teachers would lack a necessary foundation.

3.4 Application Adaptation in the Context of Chinese UTVET

The systemic weaknesses in the current ICT Competency Framework for UTVET teachers in China, as highlighted in Section 1.1, were addressed through the proposed framework indirectly. Deep digital collaboration between teachers and students (E2), supporting active student participation in the instructional process (F), and prioritizing learner autonomy (G3 and H) are highly encouraged. The proposed framework provides a structured pathway for internalizing learner-centered educational philosophies. The proposed framework provides a structured pathway for internalizing learner-centered educational philosophies. To alleviate technological fatigue, the framework offers multi-dimensional support across psychological, knowledge, and skill domains (A and B), empowering UTVET teachers in China to transition from passive, compliance-oriented training toward intrinsic professional growth (D). Furthermore, by emphasizing digital citizenship (C) and promoting reflective practice (F5), teachers are equipped to model ethical digital behaviors and design reflective learning activities, directly fostering students' ethical awareness and positive behavioral development in digital environments (G). In terms of digital competence development, the framework enables UTVET teachers in China to systematically acquire, process, and critically evaluate digital information (A, B, E, and F), ensuring that technology-enhanced learning remains grounded in authentic industrial practices. It further supports innovation and sharing of digital resources (C3, C4, E, and D), while strengthening the capacity for practical application of digital tools in teaching contexts. Finally, the framework promotes interdisciplinary and cross-institutional collaboration (C, D, and E), enhancing both internal and external digital connectivity within the TVET ecosystem.

The framework further operationalizes the principles of industry integration in TVET education settings and research-education convergence (Chen & Ma, 2023; Han & Yan, 2024; Sun et al., 2022). Through systematic digital communication and collaboration with industry experts, UTVET teachers in China are able to better identify real-world ICT competencies requirements. This professional understanding facilitates the pedagogical integration of industry-relevant in workshop-based teaching practices, thereby effectively bridging school instruction with authentic industrial demands to support students' development. Moreover, when UTVET teachers in China assume the role of "digital researchers" in industrial innovation processes, real-world research outputs can be translated into practice-oriented instructional materials Li, 2024a; Xu & Qiao, 2023). This translation is particularly vital in technical domains, such as 3D CAD modelling, where teachers must utilize contextual knowledge elements to bridge the gap between theoretical software operation and the visualization skills required in practicing engineering environments (Adnan et al., 2019, 2024). Students' learning sessions are guided and transformed from passive learning toward the resolution of authentic industrial problems by converting these outputs into project-based learning tasks within workshop environments in TVET settings. In this process, research outcomes are transformed into instructional resources that directly support students' ICT development competencies rather than remaining as theoretical outputs.

Furthermore, by leveraging ICT tools to construct open and collaborative learning environments, the framework enhances teacher-student interaction and shifts learners from passive recipients to active participants in the learning process. Students are thereby positioned as emerging professionals capable of engaging in structured communication with both educators and industry stakeholders. Overall, the proposed framework challenges the traditional linear "industry–teacher–student" transmission model in TVET. Instead, it promotes a decentralized and multidirectional collaboration structure that strengthens interaction among teachers, students, and industry partners. In practice, teacher–industry interactions are operationalized through joint curriculum co-design, industry-sponsored research, and corporate technical attachments, while student–industry interactions are realized via authentic enterprise project-based tasks, industry-mentored virtual simulations, and workplace internship evaluations. Through the formation of interconnected networks (teacher–industry, student–teacher, and student–industry), a more dynamic and data-informed symbiosis between education and industry is achieved (Guo, 2023; Li, 2024a).

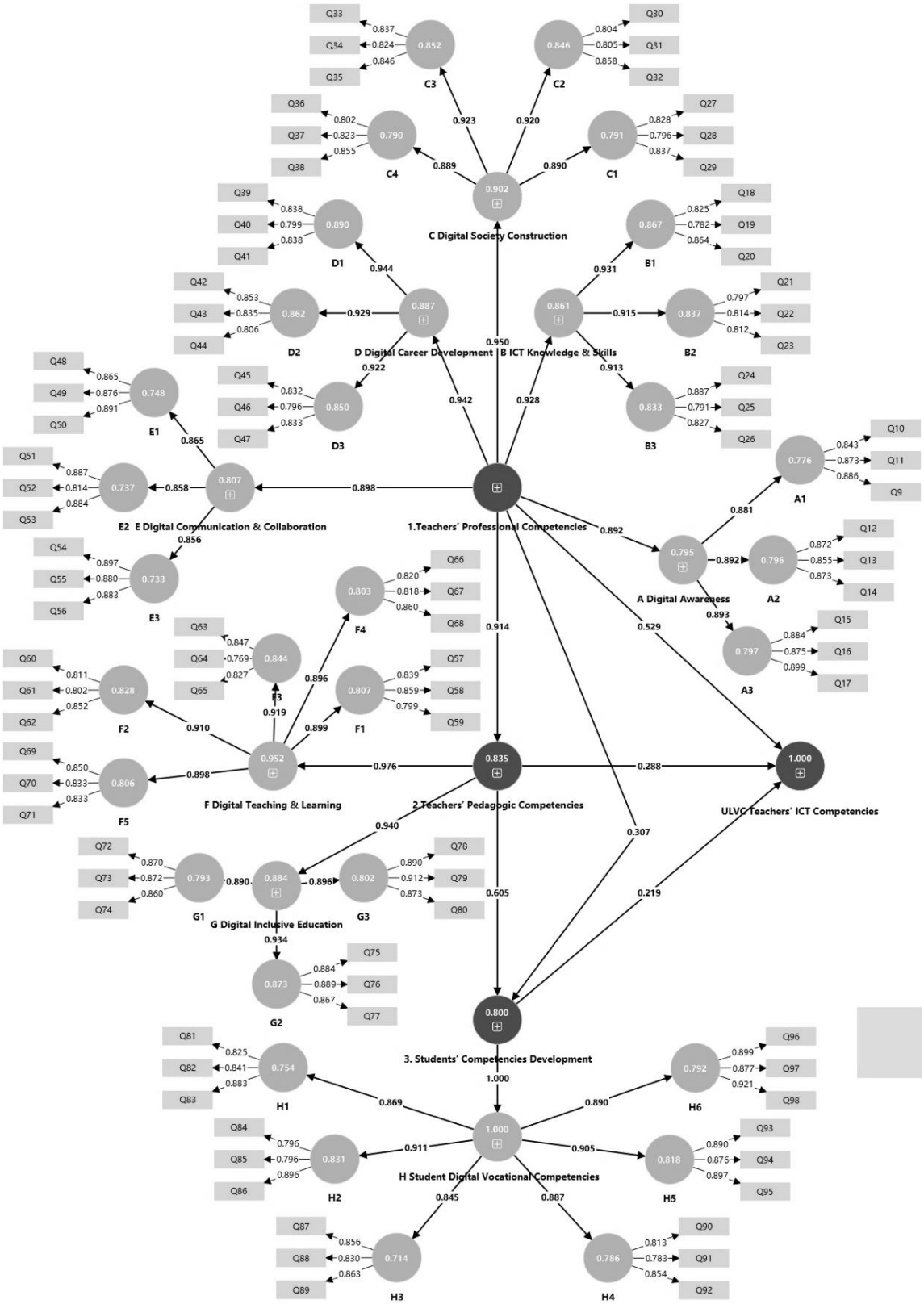


Fig. 3 *The structural model of UTVET teachers' ICT competencies*

4. Conclusion

In response to the growing importance of ICT competencies among UTVET teachers and the lack of a context-specific framework in China, this study developed and validated a comprehensive four-level ICT competencies model for UTVET teachers. As illustrated in Figure 4, the framework consists of 30 sub-competencies, 8 core competencies, 3 overarching competency domains, and an integrated holistic structure. Specifically, these 30 sub-

competencies were operationalized through 90 measurement items—retained following a modified Delphi approach and Rasch analysis—where every three items reflectively measure a single sub-competency. Using data from 400 respondents, PLS-SEM structural analysis confirmed the validity and robustness of the model, demonstrating high explanatory power across a clear foundation–practice–outcome logic during UTVET teachers' digital transformation. The structural analysis further demonstrates that Teachers' Professional Competencies (TPROC) have a significant influence on Teachers' Pedagogical Competencies (TPEDC), which in turn serve as the primary pathway influencing Students' Development Competencies (SCD). This finding highlights the importance of transforming teachers' technological acceptance and professional knowledge into pedagogical practice as a prerequisite for effectively empowering students. In the context of digital transformation, this study also indicates that the traditional linear model is being replaced by a more decentralized and interactive network structure. UTVET teachers increasingly act as key nodes in linking industry and TVET ecosystem, thereby facilitating more dynamic collaboration between stakeholders and supporting the implementation of industry integration in TVET settings, and integration of research–education convergence at the instructional level. Overall, this study contributes a validated and structured ICT Competency Framework for UTVET teachers in China, offering both theoretical and practical implications for improving teacher development and supporting digital transformation in vocational education. The ICT Competency Framework developed in this study for UTVET teachers by integrating TAM, TPACK, and Connectivism into a four-level hierarchical model. The framework can be further used as a structured theoretical basis, where the methodological approach can be replicable to explore other related areas of ICT competencies in the TVET ecosystem. The proposed framework can also be used for self-assessment of UTVET teachers' ICT competencies and for guiding professional development in ICT, and provides a reference for developing ICT competencies standards and supporting industry–education integration.

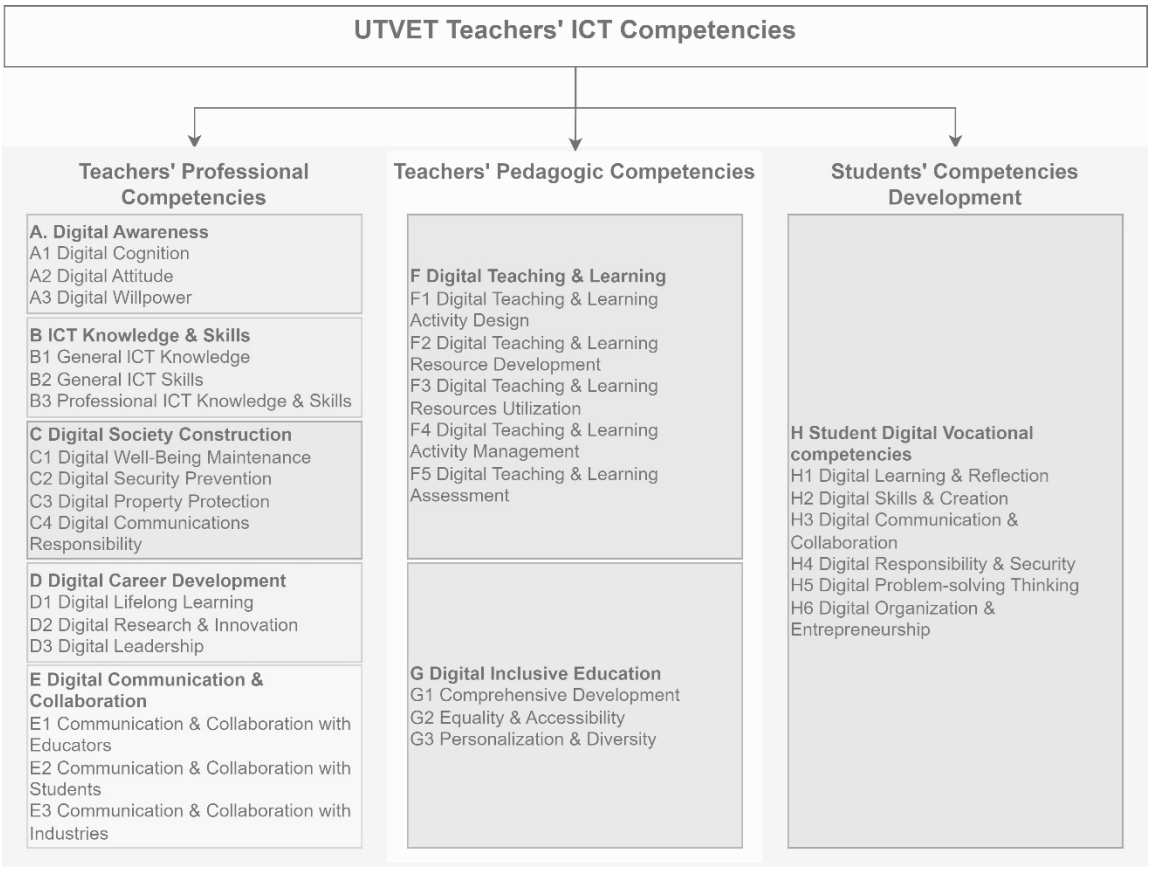


Fig. 4 *ICT competency framework for UTVET teachers in China*

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Zou Xuanyuan, Nur Hazirah Noh@Seth;* ***data collection****: Zou Xuanyuan, Li Huizhen;* ***analysis and interpretation of results****: Zou Xuanyuan, Nur Hazirah Noh@Seth, Mohd Fahmi Adnan, Hanifah Jambari, Mohamad Rasidi Pairan, Nurul Aini Mohd Ahyan;* ***draft manuscript preparation****: Zou Xuanyuan, Nur Hazirah Noh@Seth. All authors reviewed the results and approved the final version of the manuscript.*

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