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A Survey Study on the Current Status of TPACK Among Elementary Science Teachers

Yamin Wang[1]*, Dongjin Li[2], Hua Cai[1], Hong Huang[1]

[1]Academic Affairs Office, Changsha Normal University, Changsha, Hunan, China
[2]School of Primary Education, Qiongtai Normal University, Haikou, Hainan, China

***Corresponding author:** Yamin Wang, wangyamin@csnu.edu.cn

Abstract: As computer and network-based information technology exerts an increasingly widespread and profound influence on education and teaching, technology-integrated teaching methods have become the norm in modern educational practice. Proficiency in mastering and applying technological pedagogical content knowledge (TPACK) in subject teaching has become an essential competency for professional development in the new era. Based on this, this paper uses Changsha County as a case study to develop a TPACK survey questionnaire for primary school science teachers. The findings reveal that, in actual classroom teaching, older teachers demonstrate high proficiency in pedagogical knowledge, subject knowledge, and subject-specific pedagogical knowledge, but exhibit a weak understanding of, and operational skills regarding, technology. Conversely, younger teachers possess high levels of technology-related knowledge but demonstrate weaker mastery and application of pedagogical knowledge. Additionally, some teachers focus solely on subject-specific teaching tasks and are reluctant to learn new technologies. Building upon these findings, in-depth interviews were conducted to further explore the current state of TPACK proficiency among elementary science teachers and analyze the underlying causes. The study refines the investigation and proposes recommendations to enhance TPACK development among elementary science teachers, thereby promoting TPACK proficiency among practicing teachers and science education teacher candidates.

Keywords: Elementary science teacher; Pre-service teacher; Elementary science; TPACK

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1. Introduction

With the advancement of educational information technology and the rise of MOOCs, information technology has fundamentally transformed traditional classrooms, altered the methods of knowledge dissemination, and posed significant challenges to the teaching capabilities of conventional educators. Education has entered the modern era, demanding that teachers be proficient in utilizing information technology to design, organize, and implement instruction. This also requires educators to keep pace with the times, mastering and applying TPACK in their teaching practices.

TPACK stands for technological pedagogical content knowledge, representing the integration of technology with subject-specific pedagogical knowledge. The TPACK framework comprises three core elements: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK); and four composite elements: pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK) [1].

Against the backdrop of China's deepening educational technology development, TPACK has become an essential professional competency for teachers. It represents indispensable knowledge for educators in the era of educational informatization. Proficiency in TPACK and its application in teaching will become one of the standards for evaluating teachers' instructional capabilities. TPACK competence not only enables educators to adapt more swiftly and effectively to real-world teaching environments but also enhances their awareness and proficiency in educational technology, thereby preventing a disconnect between theoretical learning and practical teaching [2].

TPACK competency is particularly vital for elementary science teachers. Building a technologically advanced nation hinges on cultivating scientific talent, and science education serves as a crucial pathway for nurturing such talent and advancing technological progress. Elementary science functions as an introductory course for fostering national scientific literacy while also serving as a foundational subject for cultivating students' interest in science. Unlike other disciplines, elementary science is characterized by its strong emphasis on experimentation and inquiry. Integrating information technology with education enhances teaching efficiency and student engagement. For instance, while topics like food chains and food webs in elementary science appear straightforward, they involve substantial natural science knowledge. Teachers can leverage educational technology to create immersive learning environments, such as presenting the cyclical patterns of food chains and food webs through animations. Students can easily grasp through animations that food chains begin with producers and end with consumers, demonstrating how plants and animals mutually depend on and influence each other as integral parts of ecosystems that collectively maintain ecological balance [3]. Consequently, information technology has become a vital component of teacher professional development, and technological knowledge is inherently a crucial part of teachers' professional expertise [4].

In 2005, Mishra and Koehler expanded Shulman's Pedagogical Content Knowledge (PCK) framework to introduce Technology-Based Pedagogical Content Knowledge (TPCK), integrating educational information technology into PCK. The following year, Mishra and Koehler published a paper detailing TPCK—the knowledge of integrating technology into subject teaching—along with its components and structural framework, while outlining future research directions [5].

In 2008, Mishra integrated context into the TPACK framework, completing its definition. Subsequently, AACTE published *TPACK: A Handbook for Educators*, providing a comprehensive and systematic exposition of TPACK theory [6].

He [7] posited that TPACK represents not only a new integration of subject pedagogical content knowledge with technology but also a novel operational model for incorporating emerging educational technologies into subject curricula. His research primarily focuses on current methods for training teachers in TPACK competencies and methodologies for assessing these competencies.

Fan *et al.* [8] proposed that Primary Science Content Knowledge (PCK) refers to the teacher's ability to organize potentially obscure or complex scientific knowledge into concepts that are accessible and engaging for students. This knowledge encompasses not only the teacher's understanding of primary science content during instruction but also the evolving insights and reflections gained through teaching practice. Given that elementary science places greater emphasis on students acquiring knowledge through inquiry activities and experiments, it demands a broader knowledge base and deeper understanding from teachers compared to other subjects. Concrete, visual teaching strategies for elementary science courses are more suitable as a measure of teachers' PCK than abstract teaching plans.

Comparing domestic and international TPACK research reveals that current studies primarily focus on TPACK's structure, measuring teachers' TPACK levels, cultivating teachers' TPACK, and TPACK-based teacher education curricula. Research on elementary science teachers' TPACK remains scarce globally. This paper, integrating the current state of TPACK research globally, will investigate the current status of TPACK competencies among primary science teachers and science teacher candidates in Changsha County based on the seven components of TPACK: TK (technological knowledge), PK (pedagogical knowledge), CK (content knowledge), TPK (technology-supported content knowledge), TCK (technology-supported content), PCK (pedagogical content knowledge), and TPACK (technology-integrated pedagogical content knowledge). Based on the findings, targeted recommendations for developing primary science teachers' TPACK competencies will be proposed.

2. Distribution of the questionnaire

The survey divided the components of TPACK (TK, PK, CK, TPK, TCK, PCK, TPACK) into seven dimensions. Research was conducted through these dimensions using methods such as questionnaires and interviews with primary science teachers and science education majors in Changsha County. The questionnaire employed a five-point Likert scale [9], with five response options for each item: "Strongly agree" (5 points), "Agree" (4 points), "Somewhat agree" (3 points), "Disagree" (2 points), and "Strongly disagree" (1 point). A total of 125 questionnaires were distributed, yielding 117 valid responses with a 93.6% return rate. Data management and analysis were conducted using Excel and SPSS 20.0 software. The study examined the current state of TPACK among primary science teachers and science education majors in Changsha County, identified existing issues based on this analysis, and proposed recommendations.

To ensure questionnaire reliability, SPSS software was used to test reliability and validity prior to distribution, assessing the consistency of each item. Analysis revealed a reliability coefficient of 0.966 for the entire questionnaire. Among dimensions, PCK demonstrated the highest reliability coefficient at 0.917, while the TK dimension had the lowest reliability coefficient at 0.816. The overall reliability coefficient for the scale and its individual dimensions ranged from 0.653 to 0.966, all exceeding 0.6. These data indicate that the questionnaire content is consistent and reliable. Validity refers to the effectiveness of the questionnaire. If the KMO value is high (above 0.7), it indicates suitability for quantitative analysis. Analysis results show the scale's KMO value is 0.939, indicating accurate and reliable questionnaire responses with significant value.

3. Basic information of primary science teachers in Changsha County

Among the 117 valid questionnaires collected, the gender ratio showed significant disparity: female teachers accounted for approximately 64.11% of respondents, while male teachers constituted about 35.90%. Among active teachers, female teachers outnumbered males by 11.97%, while female teacher education students exceeded males by 16.24%. This indicates that female primary science teachers significantly outnumber their male counterparts in Changsha County, and female pre-service science teachers also substantially exceed males.

Among the surveyed elementary science teachers, those aged 20–30 constituted the largest group at

64.58%. Teachers under 20 and over 50 each accounted for 4.17% of the total, indicating a predominance of young teachers in Changsha County's elementary science teaching workforce.

Teachers with 0–5 years of teaching experience constituted the largest group at 41.67%, followed by those with 6–10 years of experience at 31.25%. Teachers with 16 or more years of experience represented the smallest group at only 4.17%. This indicates that primary science teachers in Changsha County are predominantly young educators with relatively short teaching tenures.

Among surveyed science teachers, those holding bachelor's degrees constituted the largest group at 75%, while those with associate degrees or lower accounted for only 20.83%. This indicates a high overall professional standard among science educators in Changsha County, reflecting strong teaching capabilities and advanced expertise.

Secondary-level teachers constituted the largest proportion among primary science teachers at 41.67%. This was followed by unrated teachers at 39.58%. Primary-level teachers and senior-level or above teachers accounted for 12.5% and 6.25%, respectively. This reveals that unrated teachers and primary-level teachers form the main body of primary science teachers in Changsha County.

Among surveyed elementary science teachers, 79.49% had received training in modern educational technology, while only 20.51% reported no such training. This indicates that the majority of elementary science teachers in Changsha County have undergone modern educational technology training. Additionally, it reflects the county's emphasis on teachers' ability to design, organize, and implement instruction using information technology.

4. Analysis of primary science teachers' TPACK status

First, we analyzed the average TPACK scores of elementary science teachers and science education teacher candidates across the entire TPACK framework. Subsequently, we compared the average scores of elementary science teachers and science education teacher candidates for each dimension of TPACK to identify differences in their TPACK competencies. We then conducted differential comparisons of TPACK levels between elementary science teachers and science education teacher candidates based on basic information such as age and years of teaching experience. Finally, we analyzed the correlations among the various dimensions of TPACK.

4.1. Overall mean analysis

As shown in **Table 1**, teacher education students scored higher than in-service teachers on the TK dimension. However, teachers demonstrated slightly higher overall levels than teacher education students on the PK, CK, TPK, TCK, PCK, and TPACK dimensions. The mean TPACK score for teacher education students was 2.961, while the mean TK dimension scores for in-service teachers and teacher education students were 2.924 and 2.990, respectively, both below 3 points. The highest mean score for in-service teachers was in the TPACK dimension (3.215), while the highest mean for pre-service teachers was in the PCK dimension (3.054). In-service teachers demonstrated lower technical knowledge than pre-service teachers, indicating a need for them to strengthen their mastery of technical knowledge. Teacher education students should enhance their competencies across dimensions, including subject content knowledge, pedagogical knowledge, subject pedagogical knowledge, technology-supported pedagogical knowledge, technology-supported subject content knowledge, and technology-integrated subject pedagogical knowledge—particularly knowledge related to pedagogical dimensions. In-service teachers' average scores across all dimensions ranged between 3.1 and 3.3, falling between "adequate" and "comparatively sufficient." Notably, the PK, TPK, PCK, and TPACK dimensions showed higher averages—all knowledge areas closely tied to pedagogy—indicating strong pedagogical knowledge among in-service teachers. Lower averages were observed in the TK and CK dimensions, suggesting that in-service teachers have weaker connections between technology and elementary science content. Both elementary science teachers and pre-service teachers demonstrated upper-intermediate TPACK levels, with scores across dimensions being relatively close and not significantly different. However, pre-service teachers scored slightly lower across all dimensions than in-service teachers. This suggests that teachers' knowledge reserves tend toward comprehensiveness and richness, while pre-service teachers' knowledge reserves are slightly less extensive than teachers, particularly regarding pedagogy-related knowledge, possibly due to a lack of practical teaching experience. The standard deviation for each dimension among both in-service teachers and pre-service teachers falls between 0.8 and 1.0, indicating a small deviation. This suggests that the scores of the surveyed teachers and pre-service teachers show minimal variation and are concentrated.

Table 1. TPACK mean value table

		TK	PK	CK	TPK	TCK	PCK	TPACK
In-service teachers	Mean	2.924	3.125	3.188	3.222	3.115	3.281	3.215
	Standard deviation	0.881	0.976	0.805	0.9615	0.906	0.966	0.952
Pre-service teachers	Mean	2.990	3.044	3.053	3.174	2.920	3.054	2.961
	Standard deviation	0.919	0.987	0.913	0.942	0.953	0.998	0.906

4.2. Analysis of mean scores across seven dimensions

4.2.1. Analysis of technical knowledge (TK)

As shown in **Table 2**, while pre-service teachers scored higher than in-service teachers on TK1 and TK3 dimensions, their overall technical knowledge and skills remain at a general level, indicating a need for further technical learning and refinement of technology application abilities. The highest mean score was observed on TK2, suggesting that most pre-service teachers have opportunities to use technology in elementary science teaching. The relatively lowest mean score was on TK1, indicating pre-service teachers have only a general grasp of processing and analyzing basic teaching evaluation data.

In-service teachers exhibit a higher mean for TK2 than pre-service teachers, indicating greater opportunities to use technology in elementary teaching. Conversely, their mean for TK3 is lower than that of pre-service teachers, suggesting teachers struggle to keep pace with new educational technology knowledge.

Overall, both teachers and pre-service teachers demonstrate weaker understanding and operational skills regarding technology. Given the evolving demands of teaching and rapid technological advancements, both groups should prioritize learning and practicing technological knowledge to enhance their comprehension and application of information technology [10].

Table 2. TK dimension: Mean and standard deviation

	Pre-service teachers' mean	Pre-service teachers' SD	In-service teachers' mean	In-service teachers' SD
TK1	2.930	1.005	2.920	1.048
TK2	3.040	0.992	3.100	0.881
TK3	3.000	1.111	2.750	1.263

4.2.2. Analysis of pedagogical knowledge (PK)

According to the statistical results in **Table 3**, both teachers and pre-service teachers demonstrated higher mastery levels in PK than in TK, indicating superior command of pedagogical methods. Both groups can employ diverse teaching approaches in actual classrooms and evaluate student performance from multiple perspectives. In-service teachers scored higher than pre-service teachers on the mean values of both PK1 and PK2 dimensions, suggesting more effective application of pedagogical knowledge among teachers.

Table 3. PK dimension: Mean and standard deviation

	Pre-service teachers' mean	Pre-service teachers' SD	In-service teachers' mean	In-service teachers' SD
PK1	3.09	1.095	3.15	0.989
PK2	3.00	1.029	3.10	1.134

4.2.3. Analysis of subject content knowledge (CK)

Table 4 shows that pre-service teachers scored higher on CK1 and CK2 items, indicating strong mastery of chemistry, physics, and biology content knowledge. This enables them to guide students in scientific thinking. However, their CK3 scores were slightly lower, suggesting a need to strengthen their learning of advanced science teaching concepts. In-service teachers scored higher on CK1 and CK2 but lower on CK3, indicating insufficient mastery of advanced science teaching concepts. Their mean scores for CK1 and CK3 were lower than those of pre-service teachers, suggesting weaker command of subject content knowledge in chemistry, physics, and biology, as well as advanced science teaching concepts. However, their mean score for CK2 exceeded that of pre-service teachers, demonstrating superior pedagogical knowledge and the ability to guide students in scientific thinking.

Table 4. CK dimension: Mean and standard deviation

	Pre-service teachers' mean	Pre-service teachers' SD	In-service teachers' mean	In-service teachers' SD
CK1	3.24	1.084	3.17	0.859
CK2	3.06	1.042	3.21	1.010
CK3	2.93	0.990	2.81	0.982

4.2.4. Technology-supported pedagogy knowledge (TPK)

The data in **Table 5** shows that in-service teachers scored higher than pre-service teachers on all TPK items. This indicates that in-service teachers are better equipped than pre-service teachers to select appropriate technologies to enhance teaching efficiency. Most teachers can integrate technology with the characteristics of science teaching to facilitate teacher-student and student-student interactions. Both in-service teachers and pre-service teachers scored above 3 on all items, indicating that both groups have gradually moved beyond the outdated mindset of using technology as an end in itself. They have shifted toward a rational perspective of using technology to serve the teaching process. This enables them to utilize educational technology to enhance elementary students' interest and enthusiasm for learning science, while also strengthening teacher-student and student-student interactions [11].

Table 5. TPK dimension: Mean and standard deviation

	Pre-service teachers' mean	Pre-service teachers' SD	In-service teachers' mean	In-service teachers' SD
TPK1	3.13	1.123	3.15	1.031
TPK2	3.16	0.994	3.31	0.879
TPK3	3.03	1.073	3.21	1.202

4.2.5. Technology-supported content knowledge (TCK)

Analysis of the statistical results reveals that pre-service teachers are unfamiliar with educational technologies suitable for science instruction, possess insufficient foundational TCK, and require strengthening in their practical application of TCK (**Table 6**). While in-service teachers demonstrated higher TCK levels than pre-service teachers, their TCK2 mean score was only 3.04, indicating that in-service teachers' TCK capabilities also need improvement.

Table 6. TCK dimension: Mean and standard deviation

	Pre-service teachers' mean	Pre-service teachers' SD	In-service teachers' mean	In-service teachers' SD
TCK1	2.78	1.055	3.19	1.003
TCK2	2.67	1.110	3.04	1.148

4.2.6. Pedagogical content knowledge (PCK)

Table 7 shows that in-service teachers possess higher levels of PCK, with scores ranging from 3.17 to 3.42, indicating that most teachers selected "Somewhat agree." Overall, teachers can select appropriate teaching strategies to organize instructionally rich activities that stimulate students' interest and enthusiasm for scientific knowledge. The mean PCK dimension scores for pre-service teachers were lower than those of in-service teachers, indicating that pre-service teachers possess a lower level of subject pedagogical knowledge. Furthermore, the standard deviation for PCK3 was 1.125, suggesting significant variation in pre-service teachers' scores on this item. This indicates insufficient ability to select appropriate teaching strategies for organizing scientific content. Pre-service teachers should focus on developing their subject pedagogical competencies.

Table 7. PCK dimension: Mean and standard deviation

	Pre-service teachers' mean	Pre-service teachers' SD	In-service teachers' mean	In-service teachers' SD
PCK1	3.00	1.071	3.31	0.926
PCK2	3.12	1.105	3.23	1.189
PCK3	3.00	1.125	3.42	0.964
PCK4	3.10	1.152	3.17	1.226

4.2.7. Technology-integrated subject pedagogical knowledge (TPACK)

According to **Table 8** data, the mean TPACK dimension scores for in-service teachers range from 3.08 to 3.33. This indicates that most teachers can effectively integrate information technology, elementary science knowledge, and teaching methods within a single lesson; they are capable of using technology to make abstract knowledge concrete. The mean scores for TPACK1, TPACK2, and TPACK3 all exceed 3, indicating that teachers demonstrate above-average proficiency in integrating technology, subject content, pedagogical knowledge, and technology-integrated subject knowledge. However, pre-service teachers' TPACK means all fall below 3, with TPACK1, TPACK2, and TPACK3 scores consistently lower than those of in-service teachers. This suggests pre-service teachers need to further enhance their overall TPACK proficiency.

Table 8. TPACK dimension: Mean and standard deviation

	Pre-service teachers' mean	Pre-service teachers' SD	In-service teachers' mean	In-service teachers' SD
TPACK1	2.990	1.022	3.330	0.975
TPACK 2	2.990	1.131	3.230	1.259
TPACK 3	2.910	0.981	3.080	1.108

4.3. Differential analysis

To understand differences in TPACK competencies among teachers and pre-service teachers with varying characteristics and stages, this study utilized SPSS statistical analysis software. By comparing mean values and standard deviations, it conducted differential comparisons of TPACK levels among primary science teachers with different professional titles, years of teaching experience, ages, and educational backgrounds, as well as among pre-service teachers across different grade levels.

4.3.1. Analysis of teacher age differences

Differential analysis of means and deviations across age groups for each dimension is presented in **Table 9**.

Table 9. Analysis of teacher age differences

Teacher age		TK	PK	CK	TPK	TCK	PCK	TPACK
Under 20 years	Mean	2.666	2.750	2.833	2.666	2.750	2.750	2.833
	SD	0.471	0.354	0.236	0.471	0.354	0.354	0.236
20–30 years	Mean	2.817	2.983	3.053	3.021	2.983	3.080	2.946
	SD	0.774	0.996	0.761	0.886	0.880	0.879	0.775
30–40 years	Mean	2.500	3.000	3.166	3.333	3.083	3.291	3.277
	SD	1.329	1.304	1.225	1.491	1.281	1.470	1.452
40–50 years	Mean	3.571	3.642	3.809	3.904	3.785	4.000	4.095
	SD	0.568	0.378	0.466	0.499	0.567	0.520	0.600
Over 50 years	Mean	3.033	4.250	4.500	3.467	3.250	4.375	4.073
	SD	1.179	0.354	0.707	0.236	1.061	0.530	0.707

Overall, as teacher age increases, the mean scores for TK, PK, CK, TPK, PCK, and TPACK dimensions gradually rise for teachers under 50 years old. After age 50, the mean scores for TK, TPK, TCK, and TPACK dimensions decrease to varying degrees. Older teachers demonstrate weaker technology utilization skills compared to younger teachers and should enhance their information technology knowledge. Among these, the 30–40 age group exhibited the highest standard deviation, indicating greater variability in TPACK proficiency within this cohort. Teachers under 20 showed the lowest standard deviation, and combined with their mean scores, this suggests generally lower TPACK proficiency levels among younger educators. PK, CK, and PCK dimensions all increased with age, demonstrating that experienced teachers possess higher levels of pedagogical knowledge, subject knowledge, and subject pedagogical knowledge. Younger teachers can benefit from seeking guidance and learning from their senior colleagues. Secondly, veteran teachers should adapt their pedagogical perspectives. As educational informatization advances, technological knowledge has become a critical factor in teaching. Some veteran teachers focus solely on subject-specific instruction while resisting learning new technologies [12]. Educators should embrace lifelong learning, enhance their professional competencies, improve teaching quality, and elevate their TPACK capabilities to become "learning-oriented" teachers.

4.3.2. Analysis of differences in teaching experience

Primary science teachers with 11–15 years of experience demonstrated the highest mean scores across all dimensions (**Table 10**). Teachers with 16+ years of experience showed lower scores than those with 11–15 years across all dimensions. However, teachers with shorter tenure exhibited higher mean scores in the TK dimension, with those having 6–10 years of experience achieving the highest TK mean. This indicates that younger teachers possess greater knowledge and application of educational technology. Significant differences in TPACK competencies exist across different teaching experience levels. Teachers with longer experience demonstrate greater teaching expertise, while those with shorter experience possess stronger knowledge of educational technology. This suggests that teacher training programs should emphasize collaboration between experienced and novice teachers, fostering mutual learning and support to enhance each other's TPACK levels [13].

Table 10. Analysis of differences in teaching experience

Years of teaching		TK	PK	CK	TPK	TCK	PCK	TPACK
0–5 years	Mean	3.283	2.950	3.116	3.133	3.150	3.162	2.983
	SD	0.963	1.123	0.840	0.939	1.027	0.994	0.940
6–10 years	Mean	3. 566	2.966	3.022	2.977	2.733	2.983	2.933
	SD	0.797	0.954	0.840	1.065	0.776	0.956	0.875
11–15 years	Mean	3. 000	3.636	3.515	3.727	3.681	3.909	4.000
	SD	0.668	0.552	0.673	0.743	0.603	0.718	0.715
Over 15 years	Mean	2.642	3.250	3.333	3.166	2.500	3.250	3.333
	SD	1.650	1.061	0.943	1.179	0.000	1.061	0.943

4.3.3. Analysis of differences in teacher academic background

A variance analysis of the mean scores across dimensions for teachers with different years of experience is presented in **Table 11**.

Table 11. Analysis of differences in educational background

Highest educational attainment		TK	PK	CK	TPK	TCK	PCK	TPACK
Associate's degree or lower	Mean	2.777	2.986	3.074	3.083	3.013	3.131	2.990
	SD	0.761	0.459	0.632	0.609	0.643	0.563	0.605
Bachelor's degree	Mean	3.333	3.250	3.500	3.500	3.250	3.375	3.666
	SD	0.866	1.052	0.821	0.993	0.960	1.013	0.924
Master's degree or higher	Mean	3.366	3.600	3.533	3.666	3.450	3.800	3.933
	SD	1.414	1.061	1.179	1.650	1.061	1.237	1.414

Statistical results indicate that teachers with higher academic qualifications exhibit higher mean scores across all dimensions. However, while teachers with master's degrees or higher demonstrate the highest mean scores, their standard deviation remains notably elevated. This suggests significant variability in TPACK competency across the master's degree and above cohort. Combined with the mean analysis, the impact of academic background on teachers' TPACK abilities is primarily evident between those with bachelor's degrees or below and those with bachelor's or master's degrees and above. There are no significant differences in the abilities of teachers across dimensions between bachelor's and master's degree holders, except that the mean scores for teachers with master's degrees and above are slightly higher than those with bachelor's degrees. This indicates that teachers with associate degrees or below need to continue learning to enhance their TPACK abilities.

4.3.4. Analysis of differences by teacher professional title

Analysis of average scores across dimensions for teachers with different professional titles revealed that unclassified teachers scored lower across all dimensions, with TK and PK dimensions falling below the average (**Table 12**). This may be attributed to their shorter tenure, during which they have not yet developed teaching methods aligned with their instructional style. Excluding unrated teachers, Level 1 teachers scored higher across dimensions but exhibited greater variability. Their TK mean was 3.222, while their TCK mean reached 4.222. Moreover, their PK, CK, TPK, PCK, and TPACK dimensions all ranked highest. This may relate to age, as older teachers demonstrated weaker technological proficiency. Teachers with senior titles or above showed balanced average distributions across all dimensions, indicating well-rounded and comprehensive development in all aspects.

Table 12. Analysis of differences in professional titles

Professional title		TK	PK	CK	TPK	TCK	PCK	TPACK
Uncertified teachers	Mean	2.859	2.789	3.122	3.157	3.131	3.157	3.000
	SD	1.085	1.110	0.970	1.108	1.165	1.131	1.133
Second-level teachers	Mean	2.783	3.050	2.966	2.900	2.950	3.025	3.050
	SD	0.678	0.776	0.571	0.742	0.724	0.720	0.605
First-level teachers	Mean	3.222	4.166	3.833	4.166	3.333	4.416	4.222
	SD	0.779	0.408	0.587	0.350	0.606	0.342	0.750
Senior teachers or above	Mean	3.666	3.666	3.777	3.888	3.666	3.500	3.666
	SD	0.667	0.577	0.694	0.839	0.577	0.661	0.882

4.3.5. Analysis of grade differences among science education students

A variance analysis was conducted on the mean scores across dimensions for science education teacher candidates in different academic years, with results presented in **Table 13**. As shown below, first-year teacher candidates exhibited lower mean scores across all dimensions (ranging from 1.8 to 2.1). Mean scores increased progressively with academic year, while standard deviations decreased, indicating that TPACK competencies improve steadily throughout the four-year undergraduate program. Teacher education students should actively learn TPACK-related knowledge and strive to enhance their teaching abilities and pedagogical knowledge reserves. The TPACK competencies of third- and fourth-year students show little difference, with overall levels being comparable.

Table 13. Analysis of differences by pre-service teacher year

Pre-service teacher year		TK	PK	CK	TPK	TCK	PCK	TPACK
Freshman	Mean	1.766	1.850	2.066	2.066	1.900	1.800	2.000
	SD	0.890	0.914	0.858	1.086	0.937	0.926	0.846
Sophomore	Mean	2.555	2.555	2.555	2.666	2.555	2.611	2.518
	SD	0.957	1.236	1.179	1.155	1.236	1.200	1.119
Junior	Mean	3.275	3.327	3.356	3.540	3.224	3.370	3.252
	SD	0.679	0.827	0.756	0.626	0.774	0.795	0.795
Senior	Mean	3.365	3.428	3.317	3.412	3.142	3.404	3.206
	SD	0.640	0.531	0.591	0.649	0.692	0.625	0.591

4.3.6. Analysis of differences based on training participation

A difference analysis was conducted on the mean scores across all dimensions between in-service teachers and teacher education students regarding participation in modern educational technology training. The results are shown in **Table 14**. The results indicate that individuals who participated in modern educational technology training scored significantly higher on all dimensions than those who did not, demonstrating that such training significantly promotes the development of teachers' TPACK. Conducting modern educational technology training activities is an effective approach to cultivating teachers' TPACK competencies. This is particularly true for experienced teachers with limited technical proficiency, who can elevate their teaching capabilities through such training. Relevant education authorities should also prioritize modern educational technology training for in-service teachers to enhance their TPACK competencies.

Table 14. Analysis of differences in training participation

Training participation		TK	PK	CK	TPK	TCK	PCK	TPACK
Yes	Mean	3.147	3.290	3.279	3.426	3.198	3.384	3.290
	SD	0.762	0.829	0.713	0.768	0.781	0.806	0.768
No	Mean	2.250	2.250	2.444	2.291	2.229	2.229	2.194
	SD	1.051	1.093	1.098	1.042	1.093	1.101	1.002

4.4. Correlation analysis

A Pearson correlation coefficient with an absolute value above 0.6 indicates a correlation between two variables, signifying an association. A Pearson correlation coefficient with an absolute value above 0.8 indicates a strong correlation, reflecting a significant mutual influence.

As shown in **Table 15**, the correlation coefficients between all TPACK dimensions exceed 0.6, indicating varying degrees of correlation among these dimensions. Overall, the TPACK proficiency levels of both practicing teachers and pre-service teachers who participated in the questionnaire survey showed significant positive correlations with TK, PCK, TCK, TPK, and TPACK. Elementary science teachers can enhance their overall TPACK proficiency by improving knowledge levels across all TPACK dimensions, thereby refining related knowledge and skills. Educational authorities can also enhance the overall TPACK competence of teachers and pre-service teachers by cultivating their abilities across all dimensions of TK, PK, CK, TPK, TCK, PCK, and TPACK.

Table 15. Interdimensional correlation analysis

Correlation	TK	PK	CK	TPK	TCK	PCK	TPACK
TK	1	0.734	0.724	0.716	0.617	0.645	0.687
PK	0.734	1	0.759	0.764	0.602	0.735	0.744
CK	0.724	0.759	1	0.842	0.657	0.770	0.714
TPK	0.716	0.764	0.842	1	0.706	0.853	0.833
TCK	0.617	0.602	0.657	0.706	1	0.749	0.707
PCK	0.645	0.735	0.770	0.853	0.749	1	0.839
TPACK	0.687	0.744	0.714	0.833	0.707	0.839	1

5. Analysis of reasons behind the current status of TPACK among elementary science teachers

Although surveys have examined the current development levels of TPACK among elementary science teachers, revealing that their technology-related dimensions (TK, TCK, TPK, TPACK) lag behind other dimensions, insufficient exploration has been conducted into the reasons for this development status. Therefore, interviews with elementary science teachers were conducted to refine this survey and address its shortcomings. Recommendations for the development of TPACK among elementary science teachers are proposed based on issues identified during the interviews, aiming to better promote the advancement of their TPACK levels.

5.1. Analysis of causes behind the TK status quo among elementary science teachers

Analysis of interview data regarding TK revealed that teachers generally support integrating educational technology into classrooms. Schools possess relatively well-equipped educational technology facilities, with teachers frequently utilizing multimedia tools like projectors and interactive whiteboards. These are primarily used to demonstrate experiments through video playback and to display students' experimental and inquiry outcomes via Seewo whiteboards. Teachers should continuously refine their proficiency in educational technology tools during daily instruction to enhance their technical knowledge and skills. Analysis of interview results indicates that primary science teachers rely on a single channel for acquiring technical knowledge—primarily through school-organized modern educational technology training. Few teachers seek technical knowledge through external exchanges, learning opportunities, or competitions. Teachers should actively participate in educational technology competitions, lectures, and similar activities to improve their practical application skills and thereby enhance their overall TPACK competency.

5.2. Analysis of causes behind primary science teachers' current TPK status

Interviews revealed that during instruction, most teachers apply educational technology to teach abstract scientific concepts—particularly those unsuitable for verbal explanation alone—making abstract knowledge concrete. This approach also engages students in the learning process, boosting their initiative and interest. For instance, observing plant life cycles requires extended time for complete observation. It is illogical to attempt to observe the entire process through experiments in a single class period. Therefore, teachers can play relevant videos to clearly present the life cycle of plants to students. Furthermore, when teaching knowledge about the solar system, teachers can directly play modeling videos of the solar system to allow students to experience the awe of the universe and deepen their understanding of the relationship between planetary positions and stellar orbits. It can thus be seen that primary science teachers have a relatively high level of pedagogical knowledge of technology integration (TPK).

5.3. Analysis of causes behind primary science teachers' current TCK status

Statistical analysis of collected interview results yielded corresponding conclusions: most teachers leverage increasingly advanced educational technology in daily instruction. For instance, helping elementary students comprehend scientific phenomena remains a significant challenge for teachers. Traditionally, we relied on text and illustrations to explain scientific phenomena. Today, we can utilize online resources, PowerPoint presentations, Flash animations, and other tools to make lessons engaging and easier to comprehend. However, the interview findings reveal that teachers struggle to use educational technology to present certain abstract scientific concepts in a concrete, concise, and clear manner. Overall, the interview findings indicate that in-service teachers exhibit relatively weak TCK competencies. To effectively handle science and technology subject matter, they should continue enhancing their thinking and language skills. Only by integrating educational technology with their teaching proficiency and developing both simultaneously can they achieve greater efficiency with less effort.

5.4. Analysis of reasons behind the current state of TPACK among elementary science teachers

Interviews revealed that in practice, teachers possess practical experience in maintaining classroom discipline. They can employ effective methods tailored to specific classroom situations to manage discipline. A qualified elementary science teacher must not only impart subject-specific knowledge but also understand pedagogical approaches. Technical knowledge, pedagogical knowledge, and subject knowledge are indispensable throughout the teaching process. The teaching methods, content, and technology employed by teachers are interdependent; the key lies in their effective integration—an area where current teachers fall short. The development of teachers' TPACK competencies hinges not only on mastering knowledge across each dimension but also on integrating these dimensions into a cohesive whole.

6. Conclusion

The primary objective of this study was to investigate the current state of TPACK competency among elementary science teachers and science education teacher candidates in Changsha County, identifying existing gaps and their underlying causes. The author employed a Likert five-point scale to assess the TPACK competency levels of these groups. Following the survey, teacher interviews were conducted to gain deeper insights into the reasons behind the uneven development of TPACK competency. Data analysis yielded the following conclusions and recommendations.

6.1. Training of science education teacher candidates

Overall, primary science teachers and science education teacher candidates in Changsha County demonstrate moderate proficiency. The mean scores of teacher candidates across all dimensions are slightly lower than those of practicing teachers, indicating a noticeable gap compared to an exemplary primary science teacher. It is imperative to prioritize the training of pre-service primary science teachers. This can be achieved by refining the professional training system for science education teacher candidates, increasing theoretical coursework related to primary science subject teaching, and enhancing their TCK and PCK dimensions. These measures will collectively elevate the TPACK competencies of science education teacher candidates. Additionally, practical platforms should be provided for student teachers' learning. Strengthening ties and collaboration between teacher training institutions and elementary schools offers effective pathways for integrating theoretical knowledge into practice. Particularly during the early teaching phase, experienced teachers should provide ample support and proper guidance to student teachers. Schools can organize mentor-mentee pairings and establish collaborative groups, leveraging the strengths of experienced teachers in pedagogical knowledge and student teachers in technological expertise. Through such exchanges and cooperation, both parties can enhance their TPACK competencies.

6.2. Enhancing TPACK competence among elementary science teachers

TPACK competency is positively correlated with proficiency across all TPACK dimensions. Enhancing knowledge in each dimension contributes to the overall development of primary science teachers' TPACK. Teachers should strive to elevate their TPACK proficiency by improving knowledge in all dimensions. Although survey results indicate primary science teachers' TPACK competency exceeds the average level, it remains undeniable that their TPACK abilities fall significantly short of the demands of teaching in the era of information-based education. All new educational technologies impose additional pedagogical burdens on teachers. Their acceptance of these technologies directly impacts subject content delivery, teaching methodology implementation, and student learning outcomes in science disciplines. Teachers should strive to further elevate their TPACK proficiency, particularly in utilizing information technology for scientific research and technological innovation.

Due to geographical constraints, the diversity of the science education teacher candidate sample was somewhat limited. This study surveyed only science education teacher candidates from the author's university, with all participants originating from the same institution. This inevitably introduced potential negative impacts on the survey results, possibly causing minor deviations from actual conditions.

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Disclosure statement

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