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Are they prepared for the use of digital technology? The competencies of prospective teachers in terms of technological pedagogical content knowledge

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Abstract
Although there are many studies on the competencies of preservice science teachers in terms of technological pedagogical content knowledge, few studies have been conducted on prospective teachers in Kazakhstan. Moreover, further research is needed to gain new insights into prospective science teachers' competencies in technological pedagogical content knowledge. Therefore, this study investigated the competencies of technological pedagogical content knowledge of Kazakh pre-service teachers. The data was collected using a survey. The participants were 165 pre-service science teachers. The results showed that the TPACK competencies of the pre-service teachers had a medium level. The results regarding the effects of gender on competencies showed no statistically significant differences among the six dimensions. In addition, the results regarding students' grade levels and TPACK scores revealed no statistically significant differences in seven dimensions. The results of this study provide new insights into prospective teachers' TPACK competencies. Suggestions are made based on the results.

Keywords: technological pedagogical content knowledge, TPACK, preservice science teachers, science education, STEM education, digital technology

INTRODUCTION

Technological pedagogical content knowledge (TPACK) is a framework for understanding teachers' teaching knowledge and how teachers can proficiently incorporate technology into their instruction (Alrwaished et al., 2017). It is significant due to its focus on the integration of three core domains of teaching:

1) Content knowledge,
2) Pedagogical knowledge, and
3) Technological knowledge.

The incorporation of technology in the classroom is important for teaching science in the new digital age. Hence, teachers must teach subject matter knowledge effectively using pedagogical techniques and technology (Kadıoğlu-Akbulut et al., 2023; Uygun et al., 2023). This emphasis on technology addresses TPACK in promoting more engaging and effective classroom instruction. Prior research has demonstrated that the use of TPACK can improve students' learning outcomes, foster student engagement, and deepen their comprehension of concepts (Angraini et al., 2022). Moreover, teachers' competencies are important for an effective implementation of TPACK in a classroom environment. Research has demonstrated that prospective teachers' confidence in integrating technology for curriculum content is significantly correlated with their TPACK competencies (Zahwa et al., 2021). This link indicates that proficiency in TPACK enables more effective technology utilization to enhance student learning outcomes.

Thus, the results of prior studies explicitly indicate that teachers who possess competencies regarding TPACK can promote more effective and engaging learning environments for teaching topics effectively. In this vein, since the launch of TPACK as a new framework for teachers' knowledge for using technology

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Contribution to literature

- Studying the competencies of preservice teachers' TPACK is essential for determining whether teacher education programmes can substantially improve their ability to implement technology in classrooms. However, there is little research on the TPACK skills of preservice teachers in Kazakhstan.
- Previous studies indicate a need to examine the TPACK competencies of Kazakh preservice science teachers. What makes this study unique is that existing research has not been conducted in Kazakhstan. Therefore, it is important for current research on preservice teachers to add new findings to the literature.
- This study provides new insights into the TPACK competencies of Kazakh prospective teachers. The findings will guide educators in Kazakhstan and other countries in providing professional development for prospective teachers to create technology-enhanced classrooms

in instruction, much more research has focused on determining the competencies of preservice teachers' TPACK. This research aims to ascertain prospective teachers' competencies regarding TPACK to evaluate their ability to utilize technology in scientific education and successfully incorporate it into their instructional techniques. The TPACK framework is designed to integrate technology that enhances learning experiences and outcomes. Research indicates that prospective teachers' perceptions of TPACK considerably influence their instructional methodologies (Mai & Hamzah, 2017). Studying these perceptions has been essential for scholars because they are critical to fostering a profound comprehension of how technology can be utilized to attain educational objectives in science education.

Furthermore, teacher education programs must incorporate all three components of TPACK during teacher education programs (Chai et al., 2018). Learning environments with technology usage are essential to encourage prospective teachers to utilize technology in their instruction (Uygun et al., 2023). In addition, there is a need for pre-service teachers to have a detailed understanding of how technology can support instruction in the classrooms (Valtonen et al., 2020). From this perspective, studying the competencies of preservice teachers' TPACK is essential for determining whether teacher education programs can substantially improve the readiness of preservice teachers to implement technology in their classrooms. However, there is little research on the TPACK skills of preservice teachers in Kazakhstan. Only a few studies deal with the TPACK skills of Kazakh preservice teachers. For this reason, further research is needed to obtain new information about the TPACK skills of Kazakh preservice teachers. The results of this research will help to understand the competencies of preservice teachers concerning TPACK. Therefore, this study examines Kazakh preservice teachers' technological, pedagogical, and content knowledge competencies.

TPACK and Its Components

Koehler and Mishra (2009) explained their TPACK framework in seven dimensions of knowledge for teaching using technology. First, pedagogical knowledge (PC) is about knowing how students can learn the subject and creating a lesson plan appropriate for the course topics. A teacher possessing sufficient pedagogical expertise comprehends how students assimilate information based on their learning levels, how they internally process it, acquire competencies, and cultivate their motivation to learn. Pedagogical knowledge pertains to the methodologies employed in instructing students (Koehler & Mishra, 2008). Secondly, content knowledge (CK) pertains to comprehending fundamental concepts, theories, and research associated with the curriculum's pertinent subjects (Koehler & Mishra, 2009). This knowledge encompasses scientific methodologies, techniques, facts, and theories (Koehler & Mishra, 2009). Consequently, science educators must possess fundamental knowledge of scientific subjects to be proficiently instructed.

Third, technological knowledge (TK) encompasses conventional technologies such as books, tablets, whiteboards, smartboards, three-dimensional printers, virtual reality, and augmented reality, in addition to more sophisticated technologies like the Internet and digital video. Furthermore, TC pertains to utilizing digital technologies, transmission systems, computer hardware, and conventional software applications, including word processors, spreadsheets, browsers, and email. Koehler and Mishra (2008). Fourth, pedagogical content knowledge (PCK) includes the teacher's understanding of instructional methods and techniques and the capacity to consider student characteristics when delivering the subject matter (Shulman, 1986). PCK represents a domain that encompasses the content knowledge of the subject matter and pedagogical expertise and is the type of knowledge that enables the use of analogies, explanations, presentations, and demonstrations that define concepts (Shulman, 1986). It is essential that the teacher thoroughly knows and has a good command of the subject matter he or she is expected to teach students. Pedagogical knowledge transfers knowledge of the subject with appropriate strategies within the goals and vision of the curriculum. PCK represents an area that encompasses the content knowledge of discipline and pedagogical expertise and is the type of knowledge that enables the use of analogies, explanations, presentations, and demonstrations that define concepts (Shulman, 1986). Fifth, technological content knowledge (TCK) involves the comprehension of the interrelationship between technology and subject matter. Consequently, teachers must understand the subject matter they are instructing and the methodologies employed through technological applications (Koehler & Mishra, 2008).

Sixth, technological pedagogical knowledge (TPK) encompasses utilizing technological tools effectively in a pedagogical context while recognizing their inherent limitations (Koehler & Mishra, 2009). Identifying and employing appropriate technologies to fulfill course objectives, such as collaborative homework processing (Koehler & Mishra, 2008), is imperative. Finally, technological pedagogical content knowledge (TPACK) is derived from the interplay of subject matter, pedagogical, and technological knowledge, in addition to the three primary elements of knowledge. The representation of concepts through technology, the application of suitable technologies alongside relevant pedagogical knowledge in concept acquisition, the comprehension of factors facilitating or hindering student learning, awareness of students' preparedness and prior experiences, understanding of diverse learning styles, and the solutions that technology provides to everyday challenges (Koehler & Mishra, 2008).

Recently, Petko et al. (2025) introduced a novel conceptual synthesis that integrates two essential approaches to study the effects of context in TPACK. These are contexts as external influences and contextual knowledge (XK) as an independent domain. They contended that TPACK functions concurrently as teacher knowledge influenced by external contexts, including contextualized expertise and contextual knowledge as knowledge about the educational environment. Their novel conceptualization offers a way to comprehend how teachers cultivate and implement their knowledge of technology integration across various educational contexts. In conclusion, the TPACK framework requires a comprehensive understanding of the interplay between technology, pedagogy, and content knowledge.

RELATED LITERATURE

Many studies have been conducted to understand the competencies of preservice teachers. For example, Fakhriyah et al. (2022) concluded that prospective elementary school teachers need to develop their TPACK skills. The study indicated that effective technological integration into the classroom requires familiarity with digital tools and a solid foundation of pedagogical strategies and content knowledge. In another research, Irmak and Tüzün (2018) examined teachers' perceptions of TPACK regarding the genetics topic and found that the mean score of the participants' overall TPACK is 4.15 out of 6. In addition, they found that TPACK dimensions contributed significantly to PSTs' subject matter knowledge in genetics. They found significant differences in mean scores by gender and grade level. The research of Nogerbek et al. (2022) assessed preservice biology teachers' levels of TPACK. Their results indicate that most preservice teachers consider themselves inadequate when appropriately combining technology and teaching methods. Most pre-service teachers consider themselves inadequate in using information and communication technologies. Koh et al. (2010) examined the profiles of pre-service teachers regarding TPACK. They found that the participants made no conceptual distinctions between TPACK and that there were some differences in their TPACK perceptions by gender. They also found that the influence of age and teacher level was not strong. Bwalya and Rutegwa (2023) compared pre-service science and mathematics teachers' self-efficacy in TPACK. Their results showed that prospective teachers have moderate TPACK self-efficacy. They also found that prospective teachers' TPACK self-efficacy in some dimensions was influenced by gender, year of study, and subject specialization.

Moreover, research has indicated that TPACK is influenced by various personal and contextual factors. For example, Can et al. (2017) examined the TPACK of prospective science teachers. The results showed that as the grade level of prospective teachers increased, so did their technological pedagogical content knowledge. In summary, the collective findings of these studies emphasize the importance of developing robust TPACK competencies in pre-service teachers. Holland and Piper (2016) developed a model that examined the relationships between factors such as attitudes, subjective norms, and perceived behavioral control concerning pre-service teachers' TPACK competencies. Their findings suggested the role of these factors in integrating technology into their pedagogical practice.

In addition, researchers have indicated the need for subject-specific teaching of TPACK. For example, the study of Benz and Ludwig (2023) examined the specific competencies for prospective physics teachers to use digital data collection systems effectively. They identified 15 critical subject-specific competencies for using these systems in laboratory situations. This study emphasizes the importance of general technological knowledge and the need for targeted training tailored to the specific requirements of physics teaching. Furthermore, science teachers' perceptions of TPACK are important to examine them in teacher education. For example, Lin et al. (2012) investigated prospective and in-service science teachers' perceptions of TPACK. Their results show the relationships between science teachers' perceptions of TPACK and teaching experience, gender, and age. The results suggest that female science teachers have higher self-confidence in their pedagogical knowledge but lower self-confidence in their technological knowledge than men. In another research, Deng et al. (2023) conducted a study with prospective chemistry teachers and found that their TPACK was significantly influenced by their experiences. The studies of these studies show a need to examine Kazakh preservice science teachers' competencies of TPACK. What makes this study is unique is that all of the existing studies were not conducted in Kazakhstan. Few researchers have focused on the competencies of preservice science teachers about TPACK. Hence, it is important to conduct further research on preservice teachers and add new findings to the literature.

METHOD

This study used a scale to collect data to answer the research questions. Surveys enable researchers to gather data from a substantial number of participants effectively. This approach is especially advantageous in education, where comprehending diverse perspectives is essential for enhancing teaching and learning methodologies. Surveys primarily offer the advantage of gathering quantitative data suitable for statistical analysis. A significant benefit of surveys is the capacity to engage a broad audience.

Participants

The participants in the study were pre-service teachers. They were preservice teachers who enrolled in a teacher education program at three public universities in Kazakhstan. These universities were Kazan State Technological University, Almetyevsk State Petroleum Institute, Kazan Federal University. They had taken courses on technology and pedagogy as part of their teacher education program. The authors invited the participants to participate in this study using Google Forms to ask participants to complete the data collection instruments. All participants voluntarily participated in the study. Before the study, participants were informed of the purpose of the research, that participation in the study was entirely voluntary, and that the data would be used for academic purposes only. Therefore, participants answered the questions with the data collection instrument voluntarily.

Data Analysis

The data obtained were analyzed using the SPSS 21 software. The differences between the mean total scores of the participants for the sub-dimensions of the technological pedagogical content knowledge self-assessment scale for the variables of gender and grade level were analyzed using a t-test for independent samples. The differences between the mean total scores of the participants for the sub-dimensions of the self-assessment scale of technological-pedagogical content knowledge for the variables gender and grade level were analyzed using a one-way analysis of variance (ANOVA).

Table 1. Descriptive analyses

TPACK Dimensions	N	Minimum	Maximum	Mean	Std. Deviation
TK	165	1.00	5.00	3.74	0.71
PK	165	1.00	5.00	3.42	0.76
CK	165	1.00	5.00	3.45	0.77
TPK	165	1.00	5.00	3.52	0.79
TCK	165	1.00	5.00	3.39	0.84
PCK	165	1.00	5.00	3.47	0.88
TPACK	165	1.00	5.00	3.18	0.95

Data Collection Instrument

For data collection, the Technological Pedagogical Content Knowledge Scale was used. It is a 5-point Likert-type scale comprising seven basic dimensions developed by Sahin (2011). The instrument consists of 47 items and seven dimensions on TPACK. A pool of 60 items was formed and reduced to 47 items after expert evaluation. The internal consistency coefficients of Cronbach's alpha were analyzed for the reliability of the scale. The Cronbach's alpha value for the entire scale was determined to be .93. The first factor of the scale, "Technology Knowledge"," had a reliability value of .91; the second factor, "Content Knowledge"," had a reliability value of .91; the third factor, "Pedagogical Knowledge"," had a reliability value of .96; the fourth factor, "Pedagogical Content Knowledge"," had a reliability value of .94; the fifth factor, "Technological Content Knowledge", had a reliability value of .91; the sixth factor, "Technological Pedagogical Knowledge", had a reliability value of .89; and the seventh factor, "Technological Pedagogical Content Knowledge", had a reliability value of .91.

RESULTS

Table 1 shows descriptive results of mean scores according to dimensions of TPACK competencies.

Table 1 presents the mean and standard deviation values of the TPACK scores obtained by participants across various dimensions. The descriptive analysis reveals that the participants scored a mean score of (3.74) in Technological Knowledge (TK), (3.42) in Pedagogical Knowledge (PK), (3.45) in Content Knowledge (CK), (3.52) in Technological Pedagogical Knowledge (TPK), (3.39) in Technological Content Knowledge (TCK), (3.47) in Pedagogical Content Knowledge (PCK), and (3.18) in the overall TPACK. According to these findings, we can infer that the TPACK competencies of the preservice teachers are at a medium level, with relatively higher proficiency in Technological Knowledge and lower proficiency in the overall TPACK dimensions.

Table 2. Results according to gender

TPACK Dimensions	Gender	N	Mean	Std. Deviation	t	p
TK	Female	120	3.74	.69	.015	.988
	Male	45	3.74	.77		
PK	Female	120	3.49	.73	2.034	.044
	Male	45	3.22	.81		
CK	Female	120	3.49	.74	1.220	.224
	Male	45	3.33	.83		
TPK	Female	120	3.55	.82	.811	.418
	Male	45	3.44	.73		
TCK	Female	120	3.45	.86	1.570	.118
	Male	45	3.22	.77		
PCK	Female	120	3.53	.84	1.399	.164
	Male	45	3.31	.98		
TPACK	Female	120	3.25	.96	1.343	.181
	Male	45	3.02	.90		

Table 2 presents the TPACK variation of participants according to gender, displaying the mean and standard deviation values for each TPACK dimension. The t-values and p-values indicate the statistical significance of the differences between male and female students. For Technological Knowledge (TK), the mean scores (M) were very similar between females (M = 3.74, SD = 0.69) and males (M = 3.74, SD = 0.77), with no significant difference (t = 0.015, p = 0.988). Pedagogical Knowledge (PK) showed a statistically significant difference (t = 2.034, p = 0.044), with females scoring higher (M = 3.49, SD = 0.73) than males (M = 3.22, SD = 0.82). Content Knowledge (CK) did not differ significantly between genders (t = 1.220, p = 0.224), with females scoring (M = 3.49, SD = 0.74) and males (M = 3.33, SD = 0.84). Technological Pedagogical Knowledge (TPK) also showed no significant difference (t = 0.811, p = 0.418), with females scoring (M = 3.55, SD = 0.82) and males (M = 3.44, SD = 0.73). Technological Content Knowledge (TCK) (t = 1.570, p = 0.118), Pedagogical Content Knowledge (PCK) (t = 1.399, p = 0.164), and the overall TPACK scores (t = 1.343, p = 0.181) also did not show significant differences between genders. Females scored (M = 3.45, SD = 0.87), (M = 3.53, SD = 0.84), and (M = 3.25, SD = 0.97) respectively, while males scored (M = 3.22, SD = 0.77), (M = 3.31, SD = 0.98), and (M = 3.02, SD = 0.90) respectively. In conclusion, except for Pedagogical Knowledge (PK), there were no statistically significant differences in TPACK dimensions according to gender. The overall TPACK competencies of participants are at a medium level, with females generally scoring higher across most dimensions.

Finally, differences between students' grade levels and TPACK scores were examined. The data obtained from the F test are presented in **Table 3**. According to the grade levels of participants, the differences in Technological Knowledge (TK) (F = 1.239, p = .297), Pedagogical Knowledge (PK) (F = 1.092, p = .363), Content Knowledge (CK) (F = .823, p = .512), Technological Pedagogical Knowledge (TPK) (F = 1.385, p = .242), Technological Content Knowledge (TCK) (F = 1.171, p = .326), Pedagogical Content Knowledge (PCK) (F = 2.183, p = .073), and overall TPACK (F = 2.120, p = .081) were not statistically significant (p > .05). Although the F-test results did not indicate significant differences, mean scores show that 3rd and 5th-grade students tended to have higher averages in the overall TPACK scale and its sub-dimensions than students in the 1st, 2nd, and 4th grades. This suggests a trend where higher grade levels might be associated with slightly higher TPACK scores, but these differences are not statistically significant.

DISCUSSION

This research examines Kazakh preservice teachers' Technological, Pedagogical, and Content Knowledge competencies. The descriptive analysis reveals that the participants scored a mean score of (3.74) in Technological Knowledge (TK), (3.42) in Pedagogical Knowledge (PK), (3.45) in Content Knowledge (CK), (3.52) in Technological Pedagogical Knowledge (TPK), (3.39) in Technological Content Knowledge (TCK), (3.47) in Pedagogical Content Knowledge (PCK), and (3.18) in the overall TPACK. According to these findings, we can infer that the TPACK competencies of the preservice teachers are at a medium level, with relatively higher proficiency in Technological Knowledge and lower proficiency in the overall TPACK dimensions. Our results are consistent with those of previous studies (Bwalya & Rutegwa, 2023; Can et al., 2017; Fakhriyah et al., 2022; Nogerbek et al., 2022). The reason for this finding could be due to the structure and content of the teacher education programs in which the participants took part. Previous studies have shown that teacher education programs have an impact on TPACK competencies (Fakhriyah et al., 2022). Thus, pre-service teachers can develop a more comprehensive understanding of how to use technology effectively when aligning technological tools with content and pedagogical strategies in teacher education programs (Holland & Piper, 2016). However, researchers have

Table 3. Results according to grade level

TPACK Dimensions	Grade level	N	Mean	Std. Deviation	F	p
TK	1	69	3.66	.64	1.239	.297
	2	25	3.87	.64		
	3	6	4.10	.65		
	4	60	3.69	.77		
	5	5	4.14	1.02		
	Total		3.49	0.88		
PK	1	69	3.40	.77	1.092	.363
	2	25	3.34	.75		
	3	6	4.00	.93		
	4	60	3.40	1.10		
	5	5	3.60	.86		
	Total		3.31	0.97		
CK	1	69	3.41	.77	.823	.512
	2	25	3.50	.57		
	3	6	3.97	.60		
	4	60	3.40	.83		
	5	5	3.50	1.08		
	Total		3.31	0.93		
TPK	1	69	3.51	.84	1.385	.242
	2	25	3.57	.57		
	3	6	4.04	.67		
	4	60	3.41	.83		
	5	5	4.00	.58		
	Total		3.71	.70		
TCK	1	69	3.38	.89	1.171	.326
	2	25	3.43	.67		
	3	6	3.71	1.17		
	4	60	3.28	.80		
	5	5	4.02	.98		
	Total		3.56	.90		
PCK	1	69	3.50	.87	2.183	.073
	2	25	3.54	.82		
	3	6	4.12	.77		
	4	60	3.27	.89		
	5	5	4.05	.94		
	Total		3.70	.86		
TPACK	1	69	3.32	.88	2.120	.081
	2	25	3.28	.75		
	3	6	3.53	1.43		
	4	60	2.91	.97		
	5	5	3.56	1.45		
	Total		3.32	1.1		

pointed out that many programs still struggle to fully integrate these components (Can et al., 2017). In addition, pre-service teachers' personal characteristics such as motivation and technological self-efficacy can significantly influence their TPACK competencies. Pre-service teachers who have higher levels of motivation and confidence in their technological abilities are more likely to embrace technology and use it effectively in their teaching practice (Benz & Ludwig, 2023). Conversely, those with lower self-efficacy may be hesitant to incorporate technology, resulting in a more superficial understanding of TPACK (Thohir et al., 2020). This relationship emphasizes the importance of personal variables and their development in teacher education to improve TPACK competencies.

Regarding the impact of gender on competencies, with the exception of one dimension of TPACK competencies (Pedagogical Knowledge), there were no statistically significant differences in TPACK dimensions as a function of gender. In general, our results suggest that there are no differences between females and males in terms of the influence on how pre-service teachers perceive and integrate technology into their pedagogical practice. This finding is not consistent with the results of previous studies (Bwalya & Rutegwa, 2023; Irmak & Tüzün, 2018; Koh et al., 2010). For example, Irmak and Tüzün (2018) found significant differences in mean scores by gender and suggested that female pre-service teachers may have less confidence in their technological pedagogical knowledge compared to their male counterparts. Koh et al. (2010) found some differences in TPACK perceptions by gender. Bwalya and Rutegwa (2023) demonstrated that prospective teachers' TPACK self-efficacy was influenced by gender in some dimensions. Similarly, Can et al. (2017) indicated that gender differences in TPACK were evident in the integration of content knowledge and technology and concluded that male and female teachers approached technology use in the classroom differently. In addition, previous studies have shown that gender plays a role in the development of TPACK when it comes to contextual factors such as motivation and self-efficacy. For example, gender can significantly differentiate factors such as pre-service teachers' technological self-efficacy and motivation from their TPACK (Max et al., 2023). In addition, gender may influence the correlation between attitudes and perceived behavioral control and TPACK competencies in pre-service teachers (Holland & Piper, 2016).

Results related to grade levels and students' TPACK scores showed no statistical differences between grade levels. This result is not consistent with the results of previous studies (Can et al., 2017; Irmak & Tüzün, 2018). Irmak and Tüzün (2018), for example, found significant differences in mean scores by gender and grade level. Similarly, Can et al. (2017) indicated that as the grade level of prospective teachers increased, so did their technological pedagogical content knowledge. The results of these studies suggest that grade level may lead to different TPACK competencies, but our results do not indicate this difference. The reason for this result could be due to the background characteristics of our participants. In a previous study, Max et al. (2023) indicated that prior knowledge and experience play a crucial role in the development of TPACK in pre-service teachers. In a similar study, Irmak and Tüzün (2018) found that pre-service science teachers' understanding and application of TPACK can vary greatly depending on their subject knowledge (Irmak & Tüzün, 2018). In addition, the study by Sulistiani et al. (2024) examined the relationship between self-regulation, technology integration self-efficacy, and TPACK among pre-service elementary school teachers and found that those with higher self-regulation and self-efficacy tended to have stronger TPACK competencies. This finding suggests that psychological factors may also contribute to the observed differences in TPACK levels across grade levels. In addition, Holland and Piper (2016) examined attitudes, perceived behavioral controls, and motivation in relation to TPACK competencies among pre-service teachers. Their results show that TPACK is not a static construct but is influenced by a variety of factors such as educational context, subject matter, and individual teacher characteristics. Furthermore, our findings support the findings of Li et al. (2022) as they indicate that teachers' TPACK skills vary significantly across different stages of education and therefore require tailored approaches to TPACK development based on the specific contexts and content areas being taught.

CONCLUSION

The study of the competencies of prospective science teachers (TPACK) has become increasingly important in literature over the last decade. The results of this study continue to be important because of the need to examine the competencies of prospective teachers and to understand how they choose to integrate technology into the classroom. This study provides new insights into the TPACK competencies of Kazakh prospective teachers. We believe that our findings will serve as a guide for institutions in Kazakhstan and other countries to provide professional development for prospective teachers to create technology-enhanced classrooms. From this perspective, our research also contributes to a better understanding of how to prepare teachers to use technology in the classroom. The results of this study also promise to improve the quality of technology integration in teacher education and strengthen future teachers' knowledge, skills, and attitudes related to technology integration.

RECOMMENDATIONS

Considering the results of this study, there are several recommendations on the competencies and understanding of TPACK and preservice science teachers. First, it is already important to investigate the specific TPACK competencies that prospective teachers exhibit. As previous studies suggest, there is a need for further studies that examine the barriers to effective integration of TPACK and identify the specific areas in which prospective teachers need further training. From this perspective, researchers could use qualitative methods such as interviews and classroom observations to gain deeper insights into prospective teachers' TPACK competencies. Secondly, the role of professional development in improving prospective teachers' TPACK competencies in teacher education needs to be investigated. Future research could examine the long-term effects of professional development studies on prospective teachers' competence in integrating technology into their teaching. In addition, researchers should investigate the effectiveness of different models of professional development, such as peer mentoring or co-teaching, on TPACK competencies. Third, it is important to consider the influence of teachers' beliefs and school culture on TPACK competencies. Future research should therefore focus on the relationship between prospective teachers' beliefs and the development of their TPACK competencies, especially in different educational settings. Fourth, researchers should consider conducting future research with prospective teachers from STEM subjects. Fifth, researchers can compare whether similar results can be obtained when these variables are used in different studies within this study with the same variables. Sixth, the number of application examples should be increased by creating course books with examples of lesson plans and applications for prospective teachers' use of technology in science education. Finally, as newly proposed by Petko et al. (2025), TPACK is influenced by external contexts including contextualized knowledge and contextual knowledge. Future research should investigate the influences of contextualized knowledge and broader contexts on pre-service teachers' TPACK competencies. In this way, more information about the effects of contexts on competencies will be more meaningfully understood. In particular, Petko et al. (2024) emphasize the role of contextualized development of TPACK in teacher education for specifically applied and new contexts. Given this, it would be essential to investigate the development of TPACK competencies and skills concerning contextualized knowledge during internships and mentoring activities and in different educational contexts such as various classes, schools and subjects.

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REFERENCES

Alrwaished, N., Alkandari, A., & Alhashem, F. (2017). Exploring in- and pre-service science and mathematics teachers' technology, pedagogy, and content knowledge (TPACK): What Next? *Eurasia Journal of Mathematics, Science and Technology Education, 13*(9), 6113-6131. https://doi.org/10.12973/eurasia.2017.01053a

Angraini, E., Zubaidah, S., Susanto, H., & Omar, N. (2022). Enhancing creativity in genetics using three teaching strategies-based TPACK model. *Eurasia Journal of Mathematics Science and Technology Education*, *18*(12), Article em2196. https://doi.org/10.29333/ejmste/12697

Benz, G., & Ludwig, T. (2023). Going beyond general competencies in teachers' technological knowledge: Describing and assessing pre-service physics teachers' competencies regarding the use of digital data acquisition systems and their relation to general technological knowledge. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1180973

Bwalya, A., & Rutegwa, M. (2023). Technological pedagogical content knowledge self-efficacy of pre-service science and mathematics teachers: A comparative study between two Zambian universities. *Eurasia Journal of Mathematics Science and Technology Education*, *19*(2), Article em2222. https://doi.org/10.29333/ejmste/12845

Can, B., Erokten, S., & Bahtiyar, A. (2017). An investigation of pre-service science teachers' technological pedagogical content knowledge. *European Journal of Educational Research*, 6(1), 51–57. https://doi.org/10.12973/eu-jer.6.1.51

Chai, C. S., Koh, J. H. L., & Teo, Y. H. (2018). Enhancing and modeling teachers' design beliefs and efficacy of technological pedagogical content knowledge for 21st century quality learning. *Journal of Educational Computing Research*, *57*(2), 360-384. https://doi.org/10.1177/0735633117752453

Deng, F., Lan, W., Sun, D., & Zheng, Z. (2023). Examining pre-service chemistry teachers' technological pedagogical content knowledge (TPACK) of using data-logging in the chemistry classroom. *Sustainability*, *15*(21), Article 15441. https://doi.org/10.3390/su152115441

Fakhriyah, F., Masfuah, S., Hilyana, F. S., & Mamat, N. (2022). Analysis of technological pedagogical content knowledge (TPACK) ability based on science literacy for pre-service primary school teachers in learning science concepts. *Jurnal Pendidikan IPA Indonesia*, *11*(3), 399-411. https://doi.org/10.15294/jpii.v11i3.37305

Holland, D. D., & Piper, R. T. (2016). A technology integration education (TIE) model for millennial preservice teachers: Exploring the canonical correlation relationships among attitudes, subjective norms, perceived behavioral controls, motivation, and technological, pedagogical, and content knowledge (TPACK) competencies. *Journal of Research on Technology in Education*, *48*(3), 212-226. https://doi.org/10.1080/15391523.2016.1172448

Irmak, M., & Tüzün, Ö. Y. (2018). Investigating pre-service science teachers' perceived technological pedagogical content knowledge (TPACK) regarding genetics. *Research in Science & Technological Education*, *37*(2), 127-146. https://doi.org/10.1080/02635143.2018.1466778

Kadıoğlu-Akbulut, C., Cetin-Dindar, A., Acar-Şeşen, B., & Küçük, S. (2023). Predicting preservice science teachers' TPACK through ICT usage. *Education and Information Technologies*, *28*(9), 11269-11289. https://doi.org/10.1007/s10639-023-11657-0

Koehler, M. J., & Mishra, P. (2008). Introducing TPCK. AACTE Committee on Innovation and Technology (Ed.), *The handbook of technological pedagogical content knowledge (tpck) for educators* (pp. 3-29). Mahwah, NJ: Lawrence Erlbaum Associates.

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60-70.

Koh, J. H. L., Chai, C. S., & Tsai, C. (2010). Examining the technological pedagogical content knowledge of Singapore pre-service teachers with a large-scale survey. *Journal of Computer Assisted Learning*, *26*(6), 563-573. https://doi.org/10.1111/j.1365-2729.2010.00372.x

Li, S., Liu, Y., & Su, Y. (2022). Differential analysis of teachers' technological pedagogical content knowledge (TPACK) abilities according to teaching stages and educational levels. *Sustainability*, *14*(12), Article 7176. https://doi.org/10.3390/su14127176

Lin, T., Tsai, C., Chai, C. S., & Lee, M. (2012). Identifying science teachers' perceptions of technological pedagogical and content knowledge (TPACK). *Journal of Science Education and Technology*, *22*(3), 325-336. https://doi.org/10.1007/s10956-012-9396-6

Mai, M. Y., & Hamzah, M. (2017). Primary science teachers' perceptions of technological pedagogical and content knowledge (TPACK) in Malaysia. *European Journal of Social Sciences Education and Research*, *4*(1), 12-29. https://doi.org/10.26417/ejser.v6i2.p167-179

Max, A., Weitzel, H., & Lukas, S. (2023). Factors influencing the development of pre-service science teachers' technological pedagogical content knowledge in a pedagogical makerspace. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1166018

Nogerbek, A., Sumatokhin, S., Maimatayeva, A., Ziyayeva, G., & Childibayev, D. (2022). Future biology teachers' opinions on technological pedagogical content knowledge. *World Journal on Educational Technology Current Issues*, *14*(2), 369-379. https://doi.org/10.18844/wjet.v14i2.6971

Petko, D., Koehler, M. J., & Mishra, P. (2024). Placing TPACK in context: Looking at the big picture. *Computers and Education Open*, *7,* Article 100236. https://doi.org/10.1016/j.caeo.2024.100236

Petko, D., Mishra, P., & Koehler, M. J. (2025). TPACK in context: An updated model. *Computers and Education Open*, *8,* Article 100244. https://doi.org/10.1016/j.caeo.2025.100244

Sahin, I. (2011). Development of survey of technological pedagogical and content knowledge (TPACK). *Turkish Online Journal of Educational Technology, 10*(1), 97-105.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14. https://doi.org/10.3102/0013189x015002004

Sulistiani, I. R., Setyosari, P., Sa'dijah, C., & Praherdhiono, H. (2024). Technological pedagogical content knowledge of preservice elementary teachers: Relationship to self-regulation and technology integration self-efficacy. *European Journal of Educational Research*, *13*(1), 159-170. https://doi.org/10.12973/eu-jer.13.1.159

Thohir, M. A., Jumadi, J., & Warsono, W. (2020). Technological pedagogical content knowledge (TPACK) of pre-service science teachers: A Delphi study. *Journal of Research on Technology in Education*, *54*(1), 127-142. https://doi.org/10.1080/15391523.2020.1814908

Uygun, T., Sendur, A., Dere, R., & Ozcakir, B. (2023). Development of TPACK with Web 2.0 tools: Design-basedstudy. *European Journal of Science and Mathematics Education,* *11*(3), 445-465. https://doi.org/10.30935/scimath/12907

Valtonen, T., Leppänen, U., Hyypiä, M., Sointu, E., Smits, A., & Tondeur, J. (2020). Fresh perspectives on TPACK: Pre-service teachers' own appraisal of their challenging and confident TPACK areas. *Education and Information Technologies*, *25*(4), 2823-2842. https://doi.org/10.1007/s10639-019-10092-4

Zahwa, I., Saptono, S., & Dewi, P. (2021). The interrelation among course mastery, technology integration self efficacy, and technological pedagogical content knowledge (TPACK) of prospective science teachers. *Journal of Innovative Science Education*, *10*(1). https://doi.org/10.15294/jise.v9i2.40177