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Preservice Teachers' Technology Integration Knowledge Development in an Online Technology-Based Course

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Technology-based instruction provided during the covid-19 pandemic demonstrated the importance of teachers' technology integration knowledge. This study examines the impact of a technology-based course offered remotely during the covid-19 pandemic on preservice teachers' technology integration knowledge development. It provides a new way to conceptualize and measure preservice teachers' technology integration knowledge growth in context. Multilevel modeling analysis was conducted to analyze the data gathered from 53 preservice teachers over two-time points through a validated Technological Pedagogical Content Knowledge (TPACK) survey. The results demonstrated a significant increase in all TPACK domains. Participants' main TPACK knowledge domains were more stable than their integrated knowledge domains. It was also found that the technological knowledge (TK) domain played a more significant role in explaining the development of teachers' TPACK. TK is critical for developing pre-service teachers' TPACK integrated knowledge domains, which can explain why some preservice teachers achieve a high level of Technological Content Knowledge (TCK) and Technological Pedagogical knowledge (TPK) at each time point while others do not. The findings and their implications provide guidance for the development of preservice teachers' technological knowledge that facilitates technology-supported learning environments.

Keywords: TPACK development, TPACK domains, preservice teachers, online technology-based course, multilevel modeling analysis

INTRODUCTION

The covid-19 pandemic initiated an unprecedented shift in K12 education from brick-and-mortar instruction to online learning. This shift demonstrated the importance of K12 teachers' technology integration knowledge and the potential of technology in facilitating student learning (Bower et al., 2014; Kumala et al., 2022; Wekerle & Kollar,

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2021). To prepare future K12 teachers in the area of technology integration, researchers developed an approach that connects their knowledge of technology, pedagogy, and content (Koehler & Mishra, 2009; Saputra & Chaeruman, 2022; Tondeur et al., 2020; Voogt et al., 2013). This form of knowledge, which is referred to as Technological Pedagogical Content Knowledge (TPACK) (Mishra & Koehler, 2006), builds upon Shulman's (1986) conception of Pedagogical Content Knowledge (PCK).

Historically, teacher education focused primarily on content knowledge (Fahadi & Khan 2022; Shulman, 1986). Later, teacher education shifted focus to the knowledge of pedagogy, but viewed this form of knowledge as separate from content (Shulman, 1986). Shulman proposed a distinct form of knowledge termed Pedagogical Content Knowledge (PCK) which takes into account the specific knowledge of content that translates to effective teaching. Since the conception of PCK, emerging educational technologies have transformed the K12 classroom. The consideration of the role technology plays in educational environments prompted Mishra and Koehler (2006) to develop the TPACK theoretical framework, which allows for the consideration of both digital and non-digital tools in teaching practice. Mishra and Koehler (2006) have continued the lineage of work started by Shulman, and views the three components of knowledge (technology, pedagogy and content) not as separate, but as integrated knowledge domains required for effective technology-rich teaching.

There is limited research on how specific experiences in a technology-based course impact the development of pre-services teachers' TPACK. Moreover, little is known about the specific TPACK domains that have significant influence on pre-services teachers' overall TPACK development. The purpose of the current study is to advance the literature on preservice teachers' TPACK development by examining their TPACK domains as a result of participating in an online technology-based course offered during the COVID-19 pandemic. It uses multilevel analysis to capture the complex and dynamic nature of preservice teachers' technology integration knowledge development.

Literature Review

TPACK Framework

The TPACK framework is often used to guide preservice teachers through the process of designing technology-rich learning activities. It can be interpreted as teachers' understanding of when, where, and how to enhance student learning of content using appropriate pedagogy and supporting technologies (Tseng, 2016). Although the TPACK framework has gained recognition among researchers, educators, and teachers (Herring, Koehler, Mishra, Rosenberg, & Teske, 2016; Voogt et al., 2013; Wekerle & Kollar, 2021), it does not have an agreed upon theoretical definition. Willermark (2018) stated that TPACK is defined as either knowledge or competence of technology integration.

Willermark (2018) noted that TPACK as knowledge refers to something teachers possess, such as concepts, rules, and procedures. According to Mishra and Koehler (2006) TPACK as knowledge focuses on teachers incorporating technological knowledge into the structure of pedagogical content knowledge and the surrounding context. Conversely, TPACK based on performance is defined as competence. It highlights planning, implementing, and evaluation of teaching activities (Willermark, 2018). TPACK is defined in the current study as the knowledge required for effective technology integration including its application (Aktas & Ozmen, 2020; Mishra & Koehler 2006). It serves as a theoretical framework for understanding pre-service teachers' technology integration knowledge development, which consists of three primary bodies of knowledge: pedagogical knowledge (PK), content knowledge (CK) and technological knowledge (TK). TK refers to the knowledge of the application of technologies. PK describes the knowledge of practices, procedures, or methods necessary for teaching and learning including. CK is knowledge of the subject matter.

TPACK also includes four additional constructs: pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK) and technological pedagogical content knowledge (TPCK). PCK refers to the knowledge of teaching methods that make the subject matter more understandable to the learners. TCK is described as the knowledge of how subject matter representation is influenced by technology. TPK refers to the knowledge of the application of teaching approaches applied to the use of technology. TPCK is understood as the knowledge of using various technologies to implement teaching methods for different subject content (Kumala et al., 2022; Mishra, & Koehler, 2006; Saputra & Chaeruman, 2022) Schmid, Brianza & Petko, 2021).

Preservice Teachers' TPACK Development

Research in TPACK shifted its focus from defining TPACK domains to using the framework to examine teachers' knowledge, its development through specific technology interventions and determining the relationships between the TPACK domains (Niess, 2005; Redmond & Lock, 2019; Wang et al., 2018). Existing literature indicates three pathways to TPACK development including stand-alone technology courses, embedded instructional strategies in technology or methods courses, and field experiences (Voithofer & Nelson, 2020). Voithofer and Nelson (2020) explain there is a great emphasis on learning through experience and course/field integration. Combined strategies and conditions at the macro and micro levels are believed to advance preservice teachers' TPACK development.

The key themes that have been reported regarding preservice teachers' TPACK development include the conditions at the institutional level, such as technology planning and leadership, training, and access to resources (Tondeur, Scherer, Siddiq & Baran, 2020). The key strategies at the micro level include role modeling, reflection, instructional design, lesson plans, lesson presentation, collaboration, authentic or real class experiences and feedback (Aktas & Ozmen, 2020; Tondeur, Scherer, Siddiq & Baran, 2020; Tondeur et al., 2012). Research has reported positive relationships between these strategies and preservice teachers' TPACK development (Aktas & Ozmen, 2020). The majority of TPACK studies that surveyed preservice teachers used survey instruments with multiple subscales aligned to various TPACK domains (TK, PK, CK, PCK, TPK, TCK, TPCK).

Typically, preservice teachers’ TPACK development is measured through instruments such as self-report measures, open-ended questionnaires, classroom observations, performance assessments, interviews, or a combination of several instruments (Koehler, Shin & Mishra, 2012). Tondeur, Scherer, Siddiq and Baran (2020) reported that generally, two main categories of instruments can be distinguished in the literature: self-assessment surveys and performance-based assessments. A commonly used instrument is developed by Schmidt et al. (2009). This survey has been widely used with pre-service teachers to measure their self-assessed TPACK development.

Chai, Koh, and Tsai (2011) used the Schmidt et al. (2009) survey with some modifications to suggest preservice teachers’ technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) were significant predictors of their TPACK. Wang, Schmidt-Crawford & Jin (2018) found technological knowledge (TK) in self-reported measures of pre-service teachers’ TPACK tend to have a strong correlation with TPACK development. Literature reviews suggest that while some researchers identified preservice teachers’ knowledge development in main knowledge domains (TK, CK, PK), reporting knowledge development for the integrated TPACK knowledge domains (TCK, PCK, TPK, TPCK) remains a challenge due to insignificant results (Wang, Schmidt-Crawford & Jin, 2018). This suggests that further investigation is needed to understand preservice teachers’ TPACK development. While extensive literature exists on preservice teachers’ TPACK and their own evaluations of TPACK constructs (Voogt et al., 2013), little is known about the relationship between TPACK main domains or integrative domains and preservice teachers’ TPACK development.

Purpose

Teacher education programs recognize the importance of technology integration, but they have struggled to effectively and adequately prepare preservice teachers to integrate technology in their future classrooms. There is a need to examine the relationship between preservice teachers’ TPACK main domains (TK, PK, CK) and integrated domains (TCK, PCK, TPK, TPCK) to better understand their TPACK development and develop more effective learning opportunities. The current study builds on TPACK research that examines preservice teachers’ technology integration knowledge by providing a critical analysis of their TPACK domains as a result of participating in a technology-based course offered remotely during the COVID-19 pandemic. The following research questions guided this study:

What is the impact of a fully online technology integration course on preservice teachers’ TPACK development?

What is the nature of the relationship between preservice teachers’ TPACK main domains (TK, CK, PK) and TPACK integrated domains (PCK, TCK, TPK, TPCK) over time in a fully online technology integration course?

METHOD

Sample

The data were collected from 53 of 62 (nine students did not complete the surveys) pre-service teachers enrolled in three different sections of a two-credit instructional technology course in a university located in the Southeastern United States. The 53 participants who responded to the survey yielded a 85% response rate. Respondents identified as 81% female (n = 43) and 19% (n = 10) male. Participants were asked to complete Pamuk et al.’s (2015) TPACK survey as part of the course. The course was 15 weeks in length and occurred during the fall semester of 2020. The course is a requirement for several teacher preparation programs and is an elective in others. Due to restrictions brought on by the COVID-19 pandemic, this course was modified to be conducted asynchronously online. This was the first semester the course was offered in this modality. The third author was the instructor of this course.

Context

The asynchronous online course was delivered on an installation of the WordPress blog platform. This open-access platform was designed to allow each student to create their own blog, and then connect their blogs to the main course site. One of the primary learning objectives of the course was that students would be able to model and apply technology standards as they designed, implemented, and assessed learning experiences to engage students and improve learning and enrich professional practice. During weeks two and three, students were introduced to the TPACK framework through online texts and videos. In addition, they designed learning activities during those weeks in which they first articulated the pedagogy, content and technology of each learning activity (week two), and then articulated the pedagogical content knowledge, pedagogical technological knowledge, technological content knowledge, and technological pedagogical content knowledge of a designed learning activity (week 3).

In the remainder of the course, students’ learning in this area was reinforced as they developed technology-rich learning activities using a variety of technologies (ie. Google classroom, social media, digital online resources, and the google suite of digital tools), and continued to articulate all components of the TPACK framework. In several assignments, students would reply to peers and provide feedback on their descriptions of the TPACK components.

Measures and Data Collection

Participants’ TPACK knowledge in the seven domains was assessed using Pamuk et al.’s (2015) instrument (See table 1). The survey includes 37 question items in total and rated on a four-point Likert scale (1 = Strongly Disagree, 4 = Strongly Agree). Participants completed the survey, which also included demographic data, during the second and the fifteenth week of the course. The table below presents sample item questions and number of items aligned to each TPACK domain.

Table 1
TPACK survey sample question items

Knowledge domain	Number of items	Alpha	Sample item
TK	4	.75 .84	I have sufficient knowledge and experiences with the most recent technologies.
CK	8	.82 .85	I understand the structure (organizations) of topics of content I teach.
PK	4	.86 .85	I can use different approaches to teach.
PCK	6	.78 .83	I can select teachable content of the subject matter appropriate to students' level.
TPK	4	.86 .83	I can use technology to identify individual differences among students."
TCK	4	.87 .87	I can use technology to present the content in different ways.
TPCK	7	.86 .91	I can use technology in teaching the specific content within the defined pedagogical approach in a given context.

Data Analysis

Multilevel modeling (MLM) was employed to examine changes in each preservice teachers' TPACK domain over the time frame of the course. The strategy for model building was developed in line with Hoffman's (2015) recommendations. In the first step, an empty means, random intercept model was built to inspect the intraclass correlation coefficient (ICC). In the second step, a fixed linear time, random intercept model was built to examine any linear changes in each TPACK integrated domain over time on average. Random linear time models were not permitted given the data only contained two time points. In the third step, fixed time-varying predictors were entered into the model with the integrated knowledge domains as the outcome variable based on a transformative view of the TPACK model (Schmid et al., 2020). Person-mean-centering was implemented for the level-1 predictors to separate the between-person and with-person effects of the time-varying predictors (Hoffman, 2015). Owing to the relatively small sample of the data, restricted maximum likelihood (REML) was used. Fixed effects were evaluated using Wald tests. Stata 16 was used for all the analyses.

RESULTS

Descriptive Statistics and Bivariate Correlation

Table 2 presents the descriptive statistics and bivariate correlation for each TPACK domain at each time point. No variables were substantially non-normal. Descriptively, there was an increase in all TPACK domains. TPACK domains were more strongly correlated with one another at the same data point. All the TPACK domains were significantly correlated with one another at the second time point.

Table 2
Descriptive statistics and bivariate correlation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
TK1	—													
CK1		—												
PK1		0.21	—											
PCK1	0.14	0.56*	0.50*	—										
TPK1	0.25	0.08	0.31*	0.24	—									
TCK1	0.36*	0.43*	0.43*	0.43*	0.52*	—								
TPCK1	0.34*	0.22	0.50*	0.42*	0.77*	0.66*	—							
TK2	0.35*	0.08	-0.09	-0.11	-0.05	0.09	0.06	—						
CK2	0.23	0.49*	0.04	0.20	-0.07	0.41*	0.10	0.35*	—					
PK2	0.10	0.18	0.47*	0.15	0.38*	0.49*	0.41*	0.39*	0.30*	—				
PCK2	0.13	0.25	0.37*	0.23	0.11	0.23	0.23	0.42*	0.32*	0.63*	—			
TPK2	0.11	0.01	0.22	-0.13	0.24	0.19	0.21	0.48*	0.32*	0.56*	0.43*	—		
TCK2	0.09	0.22	0.09	0.04	-0.04	0.19	0.09	0.48*	0.47*	0.54*	0.48*	0.66*	—	
TPCK2	0.06	0.12	0.17	0.09	0.04	0.23	0.11	0.52*	0.41*	0.64*	0.63*	0.66*	0.77*	—
Mean	2.97	3.10	3.10	2.90	2.93	3.22	2.98	3.23	3.19	3.36	3.18	3.46	3.43	3.31
SD	0.47	0.37	0.44	0.41	0.48	0.48	0.40	0.49	0.33	0.42	0.37	0.44	0.43	0.41
Min	1.75	2.25	2.00	2.00	1.75	2.00	2.14	2.00	2.50	3.00	2.33	2.75	2.75	2.71
Max	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Skewnes	-0.05	0.16	0.23	0.09	0.24	0.12	0.49	-0.13	0.79	0.63	0.85	0.09	0.17	0.58
Kurtosis	3.10	2.60	3.64	2.87	3.60	2.46	3.30	2.93	2.91	1.71	3.33	1.35	1.38	1.82

Note. * p<0.05

Changes in TPACK

In the first step, a series of empty means, random intercept models were built for each knowledge domain to obtain the intraclass correlation coefficient (ICC). As Table 3 shows, for main knowledge domains, around 27-45% of the original outcome variation is cross-sectional and due to between-person mean differences over time. On the contrary, for the integrated knowledge domains, about 87-99% of the original outcome variation is longitudinal and due to the variation around person means. In the second step, a series of fixed linear time, random intercept models were built to evaluate the average change in each TPACK domain from the beginning of the semester to the end of the semester. As shown in Tables 4, 5, and 6 it was found there was a significant increase in each TPACK domain from Time 1 to Time 2. Participants reported having the highest increase in TPK (Pseudo-R2 for residual variance = .43) and least in CK (Pseudo-R2 for residual variance = .12).

Table 3
Intraclass correlation coefficients

TPACK Domains	ICC
TK	.27
CK	.45
PK	.35
PCK	.06
TCK	.13
TPK	.00
TPCK	.00

Table 4
Change in TK over time

Model Parameters	Empty Means, Random Intercept Model				Fixed Linear Time, Random Intercept Model			
	Est	*SE*	*p* <		Est	*SE*	*p* <	
Model for the Means								
γ_{00} Intercept	3.09	.05	.001		2.97	.06	.001	
γ_{10} Linear Time					.26	.07	.001	
Model for the Variance								
$\tau^2_{U_0}$ Random Intercept Variance	.07	.04	[.02	.19]	.08	.03	[.04	.19]
σ^2_e Residual Variance	.18	.04	[.12	.26]	.15	.03	[.10	.22]
REML Model Fit								
Number of Parameters	3				4			
-2LL	158.15				150.18			
AIC	164.15				158.18			
BIC	170.43				166.55			

Notes. For variance components, 95% confidence intervals are presented instead of *p*-values.

Table 5
Change in CK over time

Model Parameters	Empty Means, Random Intercept Model				Fixed Linear Time, Random Intercept Model			
	Est	*SE*	*p* <		Est	*SE*	*p* <	
Model for the Means								
γ_{00} Intercept	3.15	.04	.001		3.09	.05	.001	
γ_{10} Linear Time					.12	.05	.013	
Model for the Variance								
$\tau^2_{U_0}$ Random Intercept Variance	.06	.02	[.03	.11]	.06	.02	[.04	.12]
σ^2_e Residual Variance	.07	.01	[.05	.11]	.06	.01	[.04	.09]
REML Model Fit								
Number of Parameters	3				4			
-2LL	80.08				78.58			
AIC	86.08				86.58			
BIC	92.36				94.96			

Notes. For variance components, 95% confidence intervals are presented instead of *p*-values.

Table 6
Change in PK over time

Model Parameters	Empty Means, Random Intercept Model				Fixed Linear Time, Random Intercept Model			
	Est	*SE*	*p* <		Est	*SE*	*p* <	
Model for the Means								
γ_{00} Intercept	3.22	.05	.001		3.11	.06	.001	
γ_{10} Linear Time					.26	.06	.001	
Model for the Variance								
$\tau^2_{U_0}$ Random Intercept Variance	.07	.03	[.03	.16]	.09	.03	[.05	.17]
σ^2_e Residual Variance	.13	.03	[.09	.19]	.10	.02	[.06	.14]
REML Model Fit								
Number of Parameters	3				4			
-2LL	133.69				120.92			
AIC	139.69				128.92			
BIC	145.97				137.30			

Notes. For variance components, 95% confidence intervals are presented instead of *p*-values.

Predicting TPACK

To understand the relation between TPACK knowledge domains based on a transformative view of the TPACK model, a series of fixed time-varying predictors models were built for the integrated knowledge domains: PCK, TCK, TPK, and TPCK. Each time-varying predictor was person-mean-centered to accurately evaluate the with-person and between-person effects.

It was found that for PCK at level 2 (Table 7), there was a significant between-person main effect of CK and PK, which suggested that for every one-unit higher person mean CK and PK, the mean PCK reported across two time points was expected to be higher by .39 and .44. At level 1, there was a significant within-person main effect of CK and nonsignificant within-person main effect of PK, which suggested for every one-unit more CK and PK than usual, specific time point's PCK was expected to be significantly higher by .31 and non-significantly higher by .38. The multivariate Wald test showed with four degrees of freedom that adding these time-varying variables significantly improved the prediction of the model ($p < .011$).

Table 7
Change in PCK over time and predicting PCK

Model Parameters	Empty Means, Random Intercept Model			Fixed Linear Time, Random Intercept Model			Fixed Time-Varying Predictors Model		
	Est	*SE*	*p* <	Est	*SE*	*p* <	Est	*SE*	*p* <
Model for the Means									
γ_{00} Intercept	3.03	.04	.001	2.90	.05	.001	2.38	.09	.001
γ_{10} Linear Time				.29	.06	.001	.16	.07	.021
γ_{20} WP-CK							.31	.17	.071
γ_{30} WP-PK							.38	.14	.005
γ_{01} BP-CK							.39	.10	.001
γ_{02} BP-PK							.44	.08	.001
Model for the Variance									
$\tau^2_{U_0}$ Random Intercept Variance	.01	.03	[.00 1.32]	.04	.02	[.01 .13]	.00	.01	[.00 1.15]
σ^2_e Residual Variance	.16	.03	[.11 .24]	.11	.02	[.08 .17]			[.06 .13]
REML Model Fit									
Number of Parameters	3			4			8		
-2LL	122.10			109.23			62.2		
AIC	128.10			23			78.29		
BIC	134.39			125.61			95.05		

Notes. For variance components, 95% confidence intervals are presented instead of *p*-values. WP = within-person; BP = between-person

For TCK at level 2 (Table 8), there was a significant between-person main effect of TK and CK, which suggested for every one-unit higher person mean TK and CK, the mean TCK reported across two-time points was expected to be higher by .26 and .54. At level 1, there was a significant within-person main effect of TK and nonsignificant within-person main effect of CK, which suggested that for every one-unit more TK and CK than usual, that specific time point's TCK was expected to be significantly higher by .40 and non-significantly higher by .12. The multivariate Wald test showed with four degrees of freedom that adding these time-varying variables significantly improved the prediction of the model ($p < .001$).

Table 8
Change in TCK over time and predicting TCK

Model Parameters	Empty Means, Random Intercept Model				Fixed Linear Time, Random Intercept Model				Fixed Time-Varying Predictors Model			
	Est	*SE*	*p* <		Est	*SE*	*p* <		Est	*SE*	*p* <	
Model for the Means												
γ_{00} Intercept	3.32	.05	.001		3.23	.06	.001		2.77	.10	.001	
γ_{10} Linear Time					.21	.08	.008		.11	.08	.188	
γ_{20} WP-TK									.40	.15	.009	
γ_{30} WP-CK									.12	.23	.608	
γ_{01} BP-TK									.26	.10	.008	
γ_{02} BP-CK									.54	.13	.001	
Model for the Variance												
$\tau^2_{U_0}$ Random Intercept Variance	.03	.03	[.00	.25]	.04	.03	[.01	.18]	.01	.02	[.00	1.85]
σ^2_e Residual Variance	.19	.04	[.13	.28]	.17	.03	[.11	.25]	.15	.03	[.10	.22]
REML Model Fit												
Number of Parameters	3				4				8			
-2LL	149.34				145.87				117.06			
AIC	155.34				153.87				133.06			
BIC	161.62				162.25				149.82			

Notes. For variance components, 95% confidence intervals are presented instead of *p*-values. WP = within-person; BP = between-person

For TPK at level 2 (Table 9), there was a significant between-person main effect of TK and PK, which suggested for every one-unit higher person mean TK and PK, the mean TPK reported across two time points was expected to be higher by .23 and .49. At level 1, there was a significant within-person main effect of TK and nonsignificant within-person main effect of PK, which suggested that for every one-unit more TK and PK than usual, that specific time point's TPK was expected to be significantly higher by .48 and non-significantly lower by .03. The multivariate Wald test showed with four degrees of freedom that adding these time-varying variables significantly improved the prediction of the model ($p < .001$).

Table 9
Change in TPK Over Time and Predicting TPK

Model Parameters	Empty Means, Random Intercept Model			Fixed Linear Time, Random Intercept Model			Fixed Time-Varying Predictors Model		
	Est	*SE*	*p* <	Est	*SE*	*p* <	Est	*SE*	*p* <
Model for the Means									
γ_{00} Intercept	3.18	.05	.001	2.93	.06	.001	2.49	.11	.001
γ_{10} Linear Time				.53	.08	.001	.41	.08	.001
γ_{20} WP-TK							.48	.14	.001
γ_{30} WP-PK							-.03	.18	.857
γ_{01} BP-TK							.23	.10	.019
γ_{02} BP-PK							.49	.11	.001
Model for the Variance									
$\tau^2_{U_0}$ Random Intercept Variance	.00	.00		.05	.03	[.02 .17]	.03	.02	[.00 .15]
σ^2_e Residual Variance	.28	.04	[.21 .36]	.16	.03	[.11 .24]	.13	.03	[.09 .19]
REML Model Fit									
Number of Parameters	3			4			8		
-2LL	176.04			144.14			116.97		
AIC	182.04			152.14			132.97		
BIC	188.32			160.51			149.73		

Notes. For variance components, 95% confidence intervals are presented instead of *p*-values. WP = within-person; BP = between-person

For TPCK at level 2 (Table 10), there was a significant between-person main effect of PCK, and TPK, which suggested for every one-unit higher person mean PCK, TCK, and TPK, the mean TPCK reported across two-time points was expected to be higher by .27, .33, and .35. At level 1, there was a nonsignificant within-person main effect of PCK and a significant within-person main effect of TCK and TPK, which suggested for every one-unit more PCK, TCK, and TPK than usual, specific time point's TPCK was expected to be non-significantly higher by .09 and significantly higher by .25 and .50. The multivariate Wald test showed with six degrees of freedom that adding these time-varying variables significantly improved the prediction of the model (*p* < .001). TCK,

Table 10
Change in TPCK over time and predicting TPCK

Model Parameters	Empty Means, Random Intercept Model			Fixed Linear Time, Random Intercept Model			Fixed Time-Varying Predictors Model		
	Est	*SE*	*p* <	Est	*SE*	*p* <	Est	*SE*	*p* <
Model for the Means									
γ_{00}Intercept	3.14	.04	.001	2.98	.05	.001	2.48	.06	.001
γ_{10}Linear Time				.33	.07	.001	.00	.06	.982
γ_{20}WP-PCK							.09	.11	.427
γ_{30}WP-TCK							.25	.10	.014
γ_{40}WP-TPK							.50	.10	.001
γ_{01}BP-PCK							.27	.08	.001
γ_{02}BP-TCK							.33	.08	.001
γ_{03}BP-TPK							.35	.07	.001
Model for the Variance									
$\tau^2_{U_0}$ Random Intercept Variance	.00	.00		.02	.02	[.00 .22]	.00	.00	
σ^2_eResidual Variance	.19	.03	[.14 .24]	.14	.03	[.09 .21]	.05	.01	[.04 .07]
REML Model Fit									
Number of Parameters	3			4			10		
-2LL	132.22			117.42			8.52		
AIC	138.22			125.42			28.52		
BIC	144.50			133.80			49.46		

Notes. For variance components, 95% confidence intervals are presented instead of *p*-values. WP = within-person; BP = between-person.

DISCUSSION

The results of the current study present a dynamic view on pre-service teachers' TPACK development in a technology-based course through multilevel data analysis. First, it was found that participants' main knowledge domains measured at the beginning of the semester were more strongly correlated with later assessments in comparison with integrated knowledge domains. The findings suggest that the TPACK main knowledge domains seem to be more stable over time than the TPACK integrated knowledge domains. The dynamic nature of the TPACK knowledge domains implies that TPACK is an orientation more than a fixed knowledge base, which is consistent with the findings in previous studies (Wang et al., 2018). As an orientation, TPACK domains can be manipulated in ways that advance preservice teachers' knowledge development.

Second, for main knowledge domains, a sizable proportion of outcome variance was due to between-person mean differences over time as illustrated by relatively high intraclass correlation coefficients. However, for the TPACK integrated knowledge domains, only a small proportion of the outcome variance was due to between-person mean difference over time as illustrated by extremely low intraclass correlation coefficients. This suggests one reason pre-service teachers' main knowledge domains are related longitudinally is some teachers' TPACK main knowledge domains are constantly higher or lower than their peers over time, which echoes our first finding. However, the main reason pre-service teachers' integrated knowledge domains are related longitudinally is directly associated with the levels of other factors observed at each time point instead of constant between-person mean difference in these knowledge domains over time. The results of this study suggest that growth in TPACK knowledge domains can be impacted by several between and within-person contextual factors. They emphasize the importance of taking into consideration different levels of contextual factors including micro, meso, and macro levels in designing and developing online courses for preservice teachers.

Third, aligned with existing literature, the current study shows that teachers' TPACK is malleable and can be changed in only 15 weeks. There was a significant increase in all of the TPACK knowledge domains, which supports the effectiveness of our curriculum in developing pre-service teachers' TPACK. In particular, participants had the largest increase in TPK and smallest increase in CK. Given the significant relationship between TPACK and teachers' technology integration (Raygan & Moradkhani, 2020) and the malleability of TPACK (Xie et al., 2017), it is reasonable to consider TPACK as a target for intervention in teacher education programs. To facilitate the growth of preservice teachers' TPACK domains in online courses, a major strategy applied in several studies (Wang et al., 2018; Widyasari et al., 2022) is composed of actively involving the participants in technology-enhanced lessons or course design through collaboration and enactment of technology-enhanced curriculum materials. Research (Wang et al., 2018) indicates that preservice teachers are presented with opportunities in the design of technology-enhanced lessons, but they lack experience in enacting technology-based lessons. Matching preservice teachers with practicing teachers to collaborate and enact TPACK in the classroom is a promising strategy for TPACK devolvement.

Fourth, the findings of our fixed time-varying predictors model provide deeper insights into the changing nature of integrated knowledge domains. The reason PCK at Time 1 and Time 2 are related is more directly associated with teachers' PK levels at each time point instead of CK. The reason TCK at Time 1 and Time 2 are related is more directly associated with teachers' TK levels at each time point instead of CK. The reason TPK at Time 1 and Time 2 are related is more directly associated with teachers' TK levels at each time point instead of PK. Finally, the reason TPCK at Time 1 and Time 2 are related is more directly associated with teachers' TCK and TPK levels assessed at each time point instead of PCK.

Taken together, results indicate TK plays a more salient role in helping us understand why some pre-service teachers achieve a high level of TCK and TPK at each time point, while others do not. With high TCK and TPK, a teacher is also more likely to attain high TPCK at each time point. However, it is incorrect to conclude that CK and PK are not important at all. As shown in the bivariate correlation, CK and PK have a strong correlation with integrated knowledge domains. Our finding only suggests that TK is a more critical area for developing pre-service teachers' integrated knowledge domains in a technology-based course. Moreover, although the TPACK framework is built upon the foundation of pedagogical content knowledge, our study shows that TPCK is more strongly associated with TCK and TPK than PCK over time. That is, TCK and TPK are better factors than PCK to predict why a teacher can achieve high TPCK over time.

The knowledge addressed in TK is often defined as procedural knowledge (Wang et al., 2018), which encompasses the operational skills in technology use including the application of specific hard and software tools as well as troubleshooting in problematic situations (Irdalisa et al., 2020). TK, as procedural knowledge, represents a tool-focused orientation. It incorporates knowledge about how the affordances of digital technologies relate to teaching and learning requirements (Angeli & Valanides, 2009). A functional definition of TK, on the other hand, refers to a combination of conceptual, procedural, and meta-cognitive knowledge, which is a measure of competence or proficiency in the application of digital technologies to achieve certain goals and to continually adapt to changes in technology (Anderson & Krathwohl, 2001; Wang et al., 2018). Differences in the conceptualizations of TK have implications for the focus and design of online technology-focused courses developed for preservice teachers.

TK as a predictor of preservice teachers' TPACK development can inform the examination of how contextual factors such as the functionality of specific technologies, self-efficacy, and beliefs impact the technology integration process development. A preservice teacher's belief system, for example, may support or hinder the application and use of technology (Abbitt, 2011). Research (Wang et al., 2018) suggests that decisions to include technology in lesson preparation are linked to pedagogical beliefs about content and technology and they are not always guided by the affordances of technology. The important role teacher-related factors play in TPACK development should be considered in developing strategies to enhance preservice teachers' technology integration knowledge in online technology-based courses and beyond.

The study findings have two important implications for technology-based courses in teacher education programs. First, given the stability and importance of TK, stakeholders, including educators, prospective teachers, and technology-based course developers, are recommended to longitudinally assess teachers' TK to identify those who have low TK at each assessment point. Resources and support can be prioritized and first directed to this population. Second, an integrated curriculum to foster the connection between main knowledge domains is still preferred. However, over the course of the semester, it is crucial to ensure that teachers have a sufficient understanding of how to use specific technology tools through collaborative activities, lesson planning, reflection, and peer feedback that facilitates the articulation and alignment of components of the TPACK framework.

CONCLUSION, LIMITATIONS AND FUTURE STUDY

The purpose of this study was to examine preservice teachers' technology integration knowledge development through multilevel modeling in a technology-based course offered remotely during the COVID-19 pandemic. The data was collected from 53 preservice teachers at two-time points through a validated Technological Pedagogical Content Knowledge (TPACK) survey. It was found there was a strong correlation between the pre-test scores and the post-test scores of the participants' main TPACK knowledge domains. The most prominent finding of the study was that preservice teachers' TPACK is malleable and can be changed in a 15-week academic semester, which has implications for the development of preservice teachers' technology integration knowledge. Additionally, preservice teachers' technological knowledge (TK) is a critical area for developing pre-service teachers' TPACK-integrated knowledge domains.

The findings suggest a technology-based course composed of activities that facilitate the integration of components of the TPACK framework through collaboration, lesson planning, peer feedback, and application of technological tools can play a critical role in enhancing preservice teachers' technology integration knowledge. Additionally, a multilevel analysis of preservice teachers' TPACK sub-domains showed an increasing need for TPACK interventions. Well-designed TPACK-oriented courses can help future teachers develop a better understanding of the connections between their content areas, content-specific pedagogies, and technologies. It is recommended that teacher preparation programs employ the TPACK model for developing teachers' technology integration knowledge through lesson planning and the enactment of teaching methods. Preservice teachers' TPACK growth should also be based on identifying and leveraging the contribution of each TPACK knowledge domain. In other words, designing and organizing teacher education programs should address each TPACK knowledge domain in developing successful TPACK interventions through strategies such as peer feedback and collaboration.

A limitation of the present study was the data was gathered through a self-reported measure. Unlike performance-based measures which are considered be more objective, self-reported measures tend to be subjective in nature as they could be influenced by the characteristics of the context and the participants. Also, the results of this study are limited to the data collected in one academic semester. Longitudinal research that extends for more than one semester may provide insights regarding preservice teachers' technology integration knowledge development over an extended period of time, as well as the long-term impact of a technology-based course. Future research should examine changes or improvements to technology-focused courses that prepare preservice teachers for technology integration during and beyond student teaching. Data may be collected regarding preservice teachers' learning strategies, challenges, and practices that yield better outcomes. Qualitative measures such as observations and interviews can provide in-depth insights into the connections between preservice teachers' technology integration knowledge development and their various contexts or learning environments.

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Statements on ethics, open data and conflict of interest

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