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Examining Preservice Mathematics Teachers' Technological Pedagogical Content Knowledge Development in The Natural Setting of A Teacher Preparation Program

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Abstract

This study examined preservice elementary mathematics teachers' technological pedagogical content knowledge (TPACK) development throughout their final year in the natural setting of a teacher preparation program. Data were collected from 38 preservice teachers via a TPACK self-assessment scale with seven subdomains at the beginning and end of the final year of their training. Descriptive statistics, correlation, and regression analysis were used. Results showed that participants had significantly positive gains in their pedagogical knowledge (PK), technological knowledge (TK), technological pedagogical knowledge (TPK), pedagogical content knowledge (PCK), and TPACK with medium-to-large effect sizes. Correlation analysis indicated that participants developed a more integrative understanding of TPACK. Participants' TCK, TPK, and PCK were significant predictors of their TPACK at the end of the program. The teacher preparation program seems to primarily support preservice teachers' pedagogical thinking. Therefore, the results suggest enhancing the technological aspects of the program.

Keywords: Technological pedagogical content knowledge (TPACK), teacher education, TPACK development, self-perception, regression

Introduction

Societies need productive, creative, and entrepreneurial citizens for this technology-rich era. Technology has a unique role in teaching and learning mathematics concepts through visualization, representations, models, and the dynamic nature of technology (Polly & Orill, 2012). The National Council of Teachers of Mathematics (NCTM) addressed the importance of technology in mathematics classrooms and considered technology an essential resource to help students learn mathematics meaningfully and reason and communicate mathematically (NCTM, 2014). Teachers are expected to teach mathematics effectively using various technologies (Zelkowski et al., 2013). Knowing how to teach with technology differs from knowing how to use technology (Mishra &

Koehler, 2006). Therefore, determining how to help teachers develop knowledge about effective technology integration has sparked the interest of teacher educators and researchers (Figg & Jaipal, 2012; Polly et al., 2010).

Teaching with technology may have been considered a valuable but not non-compulsory component of classrooms. Most mathematics teachers reported difficulties teaching mathematics with technology as they did not learn mathematics with technology (Niess, 2008). Teachers' lack of experience in learning mathematics with technology can indicate the lack of technology in mathematics classrooms. However, the world faced a prominent issue related to online teaching during the COVID-19 pandemic. Teachers had significant challenges adapting to online teaching, which is one of the consequences of the COVID-19 pandemic. König et al. (2020) investigated to what extent early-career teachers who are accepted as "digital natives" adapted to online teaching, and they did not find sophisticated digital skills as they expected. During the pandemic, the most effective barrier to e-learning was the lack of teachers' knowledge (Almanthari et al., 2020). This finding underpins that lack of knowledge is a crucial internal barrier to teaching with technology (Mudzimiri, 2010). Teacher knowledge needed to teach with technology effectively has gained importance during the pandemic, and preparing preservice teachers (PSTs) to teach with technology, which has been investigated since the 2000s, has remained a consequential issue. To prepare teachers with essential knowledge and skills, researchers call for addressing knowledge of technology, pedagogy, and content together (Koehler & Mishra, 2008; Mouza et al., 2014; Polly et al., 2010). Technological pedagogical content knowledge (TPACK) is defined to describe the knowledge base that teachers need to use technology effectively in teaching and learning (Mishra & Koehler, 2006).

This longitudinal study investigates the changes in preservice elementary mathematics teachers' TPACK self-assessments during their final year in a four-year teacher preparation program, collecting data from participants at the beginning and end of their last year. Considering the importance of teacher preparation in preparing technology-savvy teachers, researchers have addressed the need to examine how teacher preparation programs influence PSTs' use of technology in their future teaching (Mouza et al., 2014; Shinas et al., 2015). However, the challenges that came with the pandemic made researchers examine the extent to which teacher education opportunities support teachers' mastery of the challenges they faced during online teaching (König et al., 2020). Therefore, it is crucial to determine how to provide PSTs with the necessary training, opportunities, and support in their teacher education programs to develop their TPACK (Mouza et al., 2014; Polly et al., 2010; Zelkowski et al., 2013). The field still needs longitudinal studies that investigate the approaches and contextual factors that lead to TPACK development (Hofer & Grandgenett, 2012). The starting point for determining how to develop TPACK might be considering the changes in the natural settings of teacher preparation programs without any intervention. This study addresses the changes in the natural environment of a teacher preparation program, and I hope that the findings will contribute to endeavors to prepare tech-savvy teachers.

Theoretical Framework

The knowledge needed to integrate technologies in teaching practices was included in pedagogical knowledge in the pedagogical content knowledge (PCK) framework. This framework assumes that teachers could use appropriate technologies when they need these technologies (Shulman, 1986). Technological tools and resources were relatively limited when Shulman introduced the notion of PCK (Hofer & Grandgenett, 2012). Ertmer and Ottenbreit-Leftwich (2010) argue that teachers who never use or make their students use technology could think they are doing a great job because using technology is not compulsory for good teaching in Shulman's PCK framework. With the increasing number and complexity of technologies, Mishra and Koehler (2006) suggested that technology knowledge should be added to the PCK framework and introduced the technological pedagogical content knowledge (TPACK) framework. TPACK is the teacher knowledge needed for effective technology integration (Mishra & Koehler, 2006).

The TPACK framework has three main knowledge bases and the intersections of these bases. The main knowledge bases are pedagogical knowledge (PK), content knowledge (CK), and technological knowledge (TK). Technological pedagogical knowledge (TPK), technological content knowledge (TCK), pedagogical content knowledge (PCK), and technological pedagogical content knowledge (TPACK) arise from the intersections of the main knowledge bases (Figure 1). Mishra (2019) created an upgrade on the TPACK diagram by renaming the outer dotted circle as "ConteXtual Knowledge (XK)." XK may be defined as everything from a teacher's awareness of available technologies to the teacher's knowledge of the school, district, state, or national policies they operate within (Mishra, 2019, p.1).

TPACK includes the interconnections and intersections of content, pedagogy, and technology and integrates technology, pedagogy, and mathematics (Niess, 2008). Technological pedagogical mathematical knowledge might be referred to as the knowledge of teaching mathematics with technology and includes knowledge of mathematics content that students are expected to learn, knowledge of pedagogies related to mathematics content, and knowledge of technology that is appropriate and useful to support teaching and learning mathematics (Polly, 2014).

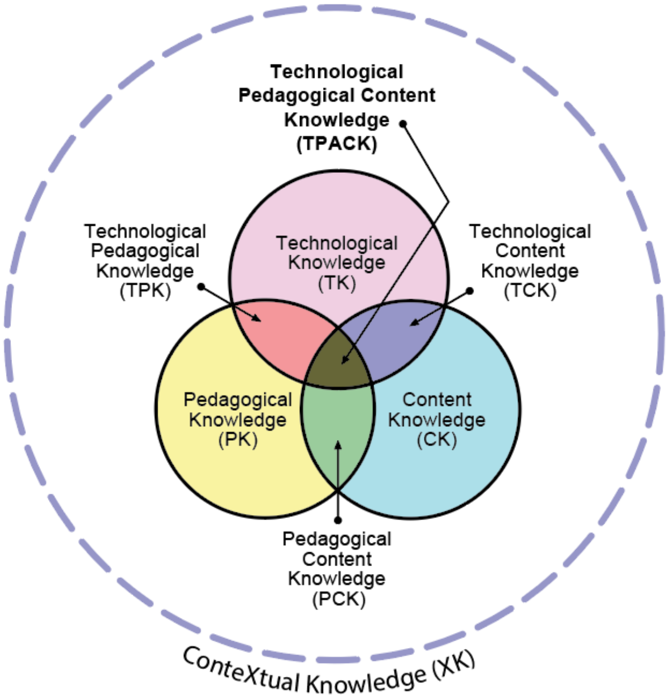

Figure 1. *TPACK Framework* (Revised version of the TPACK image. © Punya Mishra, 2018. Reproduced with permission)

Content knowledge (CK) is the subject-matter knowledge to be learned or taught and varies by subject matter and grade level (Koehler et al., 2007).

Technology knowledge (TK) is the knowledge of standard and advanced technologies. TK is essential for teachers to understand and apply information technology and identify useful technologies (Koehler & Mishra, 2008), and it also includes adaptability to rapidly changing and new technologies (Ozgun-Koca et al., 2010).

Pedagogical knowledge (PK) consists of processes, practices, and methods related to teaching objectives, values, and techniques and evaluating student learning strategies (Koehler et al., 2007; Ozgun-Koca et al., 2010). It also includes knowledge about classroom management skills, teaching strategies, and evaluation techniques (Niess, 2008).

Pedagogical content knowledge (PCK) refers to the same notion as Shulman (1986; 1987) and encompasses the teacher knowledge needed to make the content comprehensible to others. It includes knowledge of students, teaching, and content. PCK is a way to understand how teachers interpret the content, find multiple representations, and adapt educational materials for students' pre-existing knowledge (Koehler & Mishra, 2008).

Technological content knowledge (TCK) includes how technology and content reinforce and constrain each other. TCK helps teachers recognize which technology is the most useful in learning the content and how the content influences and changes technology and vice versa (Koehler & Mishra, 2008).

Technological pedagogical knowledge (TPK) is the knowledge of how teaching and learning processes change when particular technologies are used (Koehler & Mishra, 2008). TPK may be a key component in successful lesson planning and implementation (Figg & Jaipal, 2009).

Technological pedagogical content knowledge (TPACK) is the knowledge that occurs when three main knowledge domains intersect. TPACK provides us with an understanding of how these knowledge bases interact instead of considering them as separate domains (Koehler & Mishra, 2008). TPACK also serves as a framework to help teachers make effective instructional choices in technology use (Mouza et al., 2014). The more preservice teachers recognize the interactions among pedagogy, subject matter, and technology, the more they can integrate technology effectively (Angeli et al., 2016).

Teachers' TPACK plays a crucial role in deciding how to use which technologies (Mainali & Key, 2012). TPACK for mathematics teachers includes awareness about how mathematics-specific technologies improve students' mathematics learning and which topics and pedagogical practices align with specific technologies (Grandgenett, 2008). Teachers can employ digital content (websites, video clips, etc.), presentation technologies (PowerPoint, Prezi), or mathematical software (Dynamic Geometry Software, Computer Algebra Systems, Spreadsheets, etc.) in their teaching (Mouza et al., 2014). This usage ranges from using technologies as demonstration and teaching tools to inquiry and learning tools. Knowledge and beliefs play a crucial role in teachers' decisions and classroom practices. Therefore, it is essential to comprehend the process of how teachers' knowledge changes (Fives & Buehl, 2008).

TPACK Development

This section describes the approaches that promote TPACK development in teacher education and the research investigating TPACK development in mathematics teacher education. Specific approaches to help preservice and in-service teachers develop TPACK have been a focus of interest by much research (Abbitt, 2011; Açıkgül & Aslaner, 2020; Agyei & Keengwe, 2014; Agyei & Voogt, 2015; Hofer & Grandgenett, 2012; Kafyulilo et al., 2015; Meng & Sam, 2013; Mouza et al., 2014; Njiku et al., 2021; Shinas et al., 2015; Young et al., 2019). The findings of these studies contribute primarily to mathematics teacher education.

Teacher preparation programs are considered critical in preparing teachers to teach with technology effectively (Hofer & Grandgenett, 2012; Mouza et al., 2014). To prepare skilled teachers to teach with technology, teacher preparation programs mainly provide technocentric courses that focus on technical skills that develop PSTs' TK (Figg & Jaipal, 2012; Kay, 2006; Mouza et al., 2014; Polly et al., 2010). However, studies emphasize that content-centric approaches that focus on teaching specific content with technological tools may impact teachers' instructional practices with technology (Cox & Graham, 2009; Figg & Jaipal, 2012; Koh & Divaharan, 2011; Niess, 2005). Therefore, isome researchers suggest developing PSTs' TPACK via educational technology courses, content-specific teaching methods, and field experience (Abbitt, 2011; Açıkgül & Aslaner, 2020; Agyei & Voogt, 2015; Hofer & Grandgenett, 2012; Mouza et al., 2014).

Promoting PSTs' technological proficiency may be the first step to developing TPACK. Teacher preparation programs should offer PSTs experiences in learning with technology (Mudzimiri, 2010). However, researchers have observed that teachers with adequate technical proficiency fail to foster student-centered learning (Koh & Divaharan, 2011; Polly et al., 2010). After promoting technical skills, modeling how to use technology informs PSTs about how they might use technology in their future classrooms (Polly & Orill, 2012). Modeling may promote PSTs' vicarious experiences that enhance their confidence in teaching with technology (Bandura, 1977). The instructor, a cooperating teacher, or PSTs' peers may perform technology modeling. Peer learning and collaboration promote TPACK development (Koh & Divaharan, 2011). PSTs who have the opportunity to observe technology-use modeling seem to report greater technological skills and more plans about how to integrate technology (Mouza et al., 2014).

PSTs' teaching try-outs within teacher preparation courses or practicums also promote PSTs' mastery experiences and enhance TPACK development. Furthermore, PSTs should be allowed to reflect on their teaching practices. The opportunity to reflect on their practices helps PSTs develop TPACK (Figg & Jaipal, 2009; Pierson, 2008). PSTs' teaching experiences in classrooms help them transfer their theoretical knowledge into practice. Polly et al. (2010) expressed that field experience helps PSTs "witness first-hand how to integrate technology effectively into classrooms." It is also essential to consider PSTs' beliefs about the value of technology. Developing TPACK may not ensure effective technology integration unless PSTs think that technology can improve student learning (Polly et al., 2010).

Longitudinal studies examining the TPACK development of preservice mathematics teachers seem lacking. Researchers have investigated preservice mathematics teachers' TPACK development in a mathematics teaching method course (Açıkgül & Aslaner, 2020; Akkoç, 2011; Meng & Sam, 2013; Ozgun-Koca et al., 2010) or educational technology course (Agyei & Keengwe, 2014; Agyei & Voogt, 2015; Kafyulilo et al., 2015) during one semester. There is also limited research investigating TPACK development during a longitudinal study (Buss et al., 2018; Hofer & Grandgenett, 2012; Niess, 2005). Furthermore, it is also necessary to seek development in different knowledge domains, such as TPK and TCK, throughout an entire teacher preparation program (Hofer & Grandgenett, 2012).

Hofer and Grandgenett (2012) addressed TPACK development during teacher education programs and the need to investigate which areas of TPACK develop most naturally and which areas need support. These questions guided this study to trace the development of preservice mathematics teachers' TPACK during their final year of the teacher preparation program. The final year of the program offers two semesters of student teaching. Classroom-based activities reveal to what extent PSTs carry over their knowledge and skills into classrooms (Figg & Jaipal, 2012; Lawless & Pellegrino, 2007; Mouza et al., 2014; Polly et al., 2010).

This study examines the TPACK development of preservice elementary mathematics teachers during their final year by employing self-assessment tools at the beginning and end of the final year. Hofer and Grandgenett (2012) suggest using a design comparing the end of the teacher preparation program to the beginning to trace TPACK development. This study's findings may give an insight into how preservice elementary mathematics teachers' TPACK evolved naturally and which knowledge bases need to be supported. The research questions that guided the study are:

(1) Are there any significant differences in participants' TK, PK, CK, TCK, TPK, PCK, and TPACK between the beginning and end of the final year of the teacher preparation program?
(2) Are there any relationships between participants' TPACK and other knowledge bases (TK, PK, CK, TCK, TPK, PCK) at the beginning and end of the final year of the teacher preparation program?
(3) To what extent do participants' TCK, TPK, and PCK predict their self-reported TPACK at the beginning and end of the final year of the teacher preparation program?

Methods

Research Design

The study aimed to test whether the teacher preparation program's final year affected preservice elementary mathematics teachers' TPACK and used a single-group presurvey-postsurvey design to trace PSTs' perceptions of their technology integration knowledge and skills (Creswell, 2012; Fraenkel et al., 2012). The focus was on how TPACK develops naturally during the teacher preparation program's final year; therefore, a control group was not used. The relationship between TPACK domains, as well as TPACK development, was also examined throughout the study.

The Research Context

This study was conducted in a four-year undergraduate elementary mathematics teacher preparation program. PSTs had to take 146 credit hours of courses and be successful in these courses to graduate. The courses may be categorized as mathematics, technology, pedagogy, and liberal education courses. The mathematics teacher education curriculum was updated in 2018, but participants of this study received instruction based on the previous curriculum. The overview of the program coursework related to mathematics, pedagogy, and technology is given in Table 1.

Table 1. *Teacher Preparation Program Coursework*

Year	Spring		Fall	
1	Mathematics	General Mathematics	Mathematics	Discrete Mathematics Geometry
	Pedagogy	Introduction to Education	Pedagogy	Educational Psychology
	Technology	Information Technologies I	Technology	Information Technologies I
2	Mathematics	Calculus I Linear Algebra I Physics I	Mathematics	Calculus II Linear Algebra II Physics II
	Pedagogy	Research Methods in Education Instructional Principles and Methods	Mathematics-Specific Technology	Instructional Technologies and Material Design
	Mathematics-Specific Technology	Exploring Mathematical Concepts with Dynamic Geometry Software		
3	Mathematics	Calculus III Analytic Geometry I Statistics and Probability I Introduction to Algebra	Mathematics	Analytic Geometry I Statistics and Probability I Differential Equations
	Pedagogy	Educational Sociology	Pedagogy	Turkish Education History Measurement and Assessment of Learning
	Mathematics-Specific Pedagogy	Mathematics Teaching Methods I	Mathematics-Specific Pedagogy	Mathematics Teaching Methods II
4	Mathematics	Elementary Number Theory History of Mathematics	Mathematics	Philosophy of Mathematics

	Pedagogy	Classroom Management Guidance Student Teaching	Pedagogy	Turkish Educational System and School Management New Approaches to Teaching Processes Student Teaching
	Mathematics-Specific Technology	Mathematics Teaching with Computer Algebra Systems		

The program mainly includes courses related to mathematics and pedagogy. There is a lack of content-specific courses. The only mathematics-specific pedagogy courses are two cohorts of mathematics teaching method courses (without practicums). PSTs learn about basic information and communication technologies and theoretical knowledge related to technology in education in their first year. The course “Exploring Mathematical Concepts with Dynamic Geometry Software” focuses on GeoGebra and its applications. PSTs are asked to design a GeoGebra material as a part of the course “Instructional Technologies and Material Design.” The program offers PSTs another mathematics-specific technology course in the final year. Additionally, technology courses occur in labs that allow PSTs to work with computers.

Data were collected at two points throughout the program: at the beginning and end of the final year of the program. Before the final year, PSTs receive most of their mathematics-specific pedagogy and technology courses. The final year includes two semesters of student teaching. In the first semester of student teaching, PSTs observe how cooperating teachers teach, assess student learning, ensure student engagement, and determine which techniques and strategies they prefer in the cooperating schools. The first semester of student teaching aims to help PSTs learn about the classroom environment. In the second semester of student teaching, PSTs begin to teach in real classrooms six hours per week. The schools to which the PSTs were assigned for student teaching had smartboards, digital content, and specific software in their classes. However, it is worthwhile noting that no further information about technology use by cooperation teachers or student teachers was collected.

Participants

Participants were final-year PSTs from a single cohort group in the mathematics education department of a teacher preparation program in Middle Anatolia, Turkey. Data were collected from fall 2017 through spring 2018 in a paper-pencil environment. Fifty-two PSTs were enrolled in the final year of the program. To minimize the effect of missing data, I obtained a list of students and marked those who completed the presurvey and postsurvey. Participation in the study was voluntary. Eight PSTs did not complete both the presurvey and postsurvey, and six PSTs did not complete the entire sections of the data collection tool. Therefore, data obtained from 38 PSTs were included in the data analysis. Thirty-two of the participants were female, and six were male. The participants' age ranged from 20 to 24 (M=21.921, Sd=1.238). The participants were selected as senior PSTs purposefully. The most distinguishing aspect of the final year is that preservice teachers experience schools' real context for the first time.

Data Collection Tool

Self-assessment is the process of assessing one's performance based on the criteria identified previously (Panaderoet al., 2012); includes individuals' critical thinking about their knowledge, understanding, and skills related to activity; and helps PSTs become aware of their identities and roles as professionals (Bourke, 2014). Allowing PSTs to assess their TPACK perceptions may help them think about learning to teach mathematics with technology (Panadero et al., 2013). Therefore, PSTs were asked to rate themselves according to criteria based on the TPACK framework.

Participants were invited to complete the TPACK Self-Assessment Scale (TPACK-SAS) at the beginning and end of their final year in the teacher preparation program. The TPACK-SAS was developed by Kartal et al. (2016), and the original form of the scale is written in Turkish. It consists of seven factors and 67 items. Items were measured on a 7-point Likert-type scale ranging from "strongly agree" to "strongly disagree." Table 2 presents the number of items, sample items, and Cronbach's alpha values for each factor. As Table 2 shows, reliability coefficients ranged from 0.824 to 0.931 on the presurvey and from 0.816 to 0.902 on the postsurvey. Cohen et al. (2007, p. 506) proposed the following guidelines to interpret the reliability coefficients: *> 0.90 (very highly reliable), 0.80–0.90 (highly reliable), 0.70–0.79 (reliable), 0.60–0.69 (minimally reliable), < 0.60 (unacceptably low reliability)*. Considering the reliability coefficients calculated for this study, I can say that the subdomains are highly reliable in measuring preservice elementary mathematics teachers' knowledge domains needed to integrate technology effectively.

Table 2. *Sample Items and Cronbach's Alpha for Each TPACK Subdomain*

Factor	Sample Item	Number of items	Cronbach's alpha	
			Presurvey	Postsurvey
PK	I think I can use teaching techniques, strategies and methods effectively.	15	0.912	0.848
TK	I think I have enough knowledge about leading computer software (e.g., Windows Media Player, Abode Reader, Foxit) and their features.	11	0.843	0.823
CK	I think I have enough knowledge in my content area.	8	0.859	0.869
TCK	I can reach online resources related to my subject matter.	5	0.824	0.852

TPK	I think I know how to use technology in different teaching activities.	10	0.832	0.902
PCK	I think I can develop and use different representations (e.g., visual, auditory) related to my content area.	11	0.931	0.816
TPACK	I think I can use technology effectively to meet the pedagogical needs (teaching methods, instructional materials, classroom management, student learning) when teaching a particular topic.	7	0.837	0.896

Data Analysis

A Likert scale allows researchers to transform the subjectivity of qualitative attributes such as thinking (cognition), feeling (affective), and action (psychomotor) into the objectivity of quantitative measures (Joshi et al., 2015). TPACK-SAS is a Likert scale with seven domains. The means of all subscale items for each participant were calculated for each subscale described by the survey developers. Four was considered the midpoint of the rating scale to interpret the analyzed data.

Participants were asked to write their names on their surveys to make the response-pair easy and correct. I gave a number for each participant in the presurvey. For example, I looked for the postsurvey of PST-1 and gave it the number “one.” Then I marked the participant’s name in my list, which means that the given participant’s presurvey and postsurvey were paired. Participants who did not complete both the presurvey and postsurvey were excluded from the data set. Data was imported into Excel, and participants who did not complete the entire survey sections were removed from Excel. After identifying and removing missing data, I imported the raw data into SPSS.

Kolmogorov-Smirnov tests assessed the normality of the quantitative dataset, and I calculated the skewness and kurtosis values. Kolmogorov-Smirnov ($Z = 0.920$, $p = 0.809$), skewness (0.857), and kurtosis (0.476) values showed that the data have a normal distribution. These values make it possible to use parametric tests. Descriptive analysis, including mean and standard deviation, was conducted. A paired-sample t-test was run to investigate significant differences in PSTs’ self-reported TPACK from the beginning to the end of their final year. Effect sizes were calculated by using Cohen’s d. The benchmarks provided by Cohen (1988) guide the implementation of the effect sizes. The effect size of 0.2 is considered a small effect size, 0.5 a medium, and 0.8 a large effect size.

Correlation analysis was performed to determine the relationships between the central component, TPACK, and the other knowledge bases (TK, CK, PK, TCK, TPK, and PCK). I interpreted the correlation coefficients of 0.10, 0.30, and 0.50 as small, medium, and large (Field, 2013). Multiple regression analysis was conducted to reveal to what extent PSTs’ TPK, TCK, and PCK predict their TPACK. Field (2013) proposed that having 10 or 15 cases for each predictor is a common rule to determine the sample size in regression. According to this rule, a sample size of 30–45 is enough to perform a regression analysis with three predictors. This study has 38 cases. Furthermore, the expected R is expected to approximate 0, and using the formula R=k/(N-1), the expected R is calculated as 0.08(3/[38-1]) for this study. The calculated R (.08) may be considered acceptable for a model of three predictors and 38 cases (Field, 2013). The assumptions of normality, linearity, and homoscedasticity were tested before multiple regression analysis.

Internal and External Validity

Internal validity is a crucial issue in experimental designs as it is necessary to ensure that the inferences of the study are correct. On the other hand, external validity is related to the generalizability of correct inferences from the sample to other samples (Creswell, 2012; Fraenkel et al., 2012). However, the single group presurvey-postsurvey research design is one of the least protected against factors threatening validity (Fraenkel et al., 2012). The procedures to address the threats to the internal and external validity were performed based on the recommendations (Creswell, 2012; Shadish et al., 2002) and are given as follows:

Participants had similar demographics, such as age and perceived competence in computer use. Furthermore, they experienced the same activities during their final year; in other words, they equally experienced the benefits of the teacher preparation program. These may help control the threats regarding *participants* and *treatment* (Creswell, 2012; Fraenkel et al., 2012).

The presurvey and postsurvey did not change. There were nine months between the presurvey and postsurvey. It is a sufficiently long time to prevent participants from remembering their responses for the postsurvey. The long time between the presurvey and postsurvey and not changing the presurvey and postsurvey may minimize the effect of the threats of *testing* and *instrumentation* (Creswell, 2012; Fraenkel et al., 2012). The researcher administered both the presurvey and the postsurvey to eliminate threats related to researcher bias (Creswell, 2012; Fraenkel et al., 2012).

It is worth noting that it may be difficult to generalize the inferences of this study to other mathematics teacher education programs. The results may be consistent with those with similar participants and similar coursework.

Results

Research Question 1: Are there any significant differences in participants’ TK, CK, PK, TCK, TPK, PCK, and TPACK between the beginning and end of the final year of the teacher preparation program?

Figure 2 and Table 3 demonstrate the differences in PSTs' presurvey and postsurvey TPACK scores. Figure 2 includes the mean scores and error bars representing the standard deviations of the data set. As the figure clearly shows, participants' mean scores for all subdomains increased. The presurvey mean scores ranged from 4.664 (CK) to 5.201 (PK), and postsurvey mean scores ranged from 4.763 (CK) to 5.791 (PK). The mean scores except for CK were above 5 in the presurvey and postsurvey. The teacher preparation program may have supported participants to feel confident in all TPACK subdomains until the final year. The differences in standard deviations show that the spread of preservice teachers' postsurvey mean scores became smaller than that in PK, CK, TCK, TPK, and PCK. In other words, preservice teachers' mean scores of PK, CK, TCK, TPK, and PCK were clumped around the mean of the postsurvey.

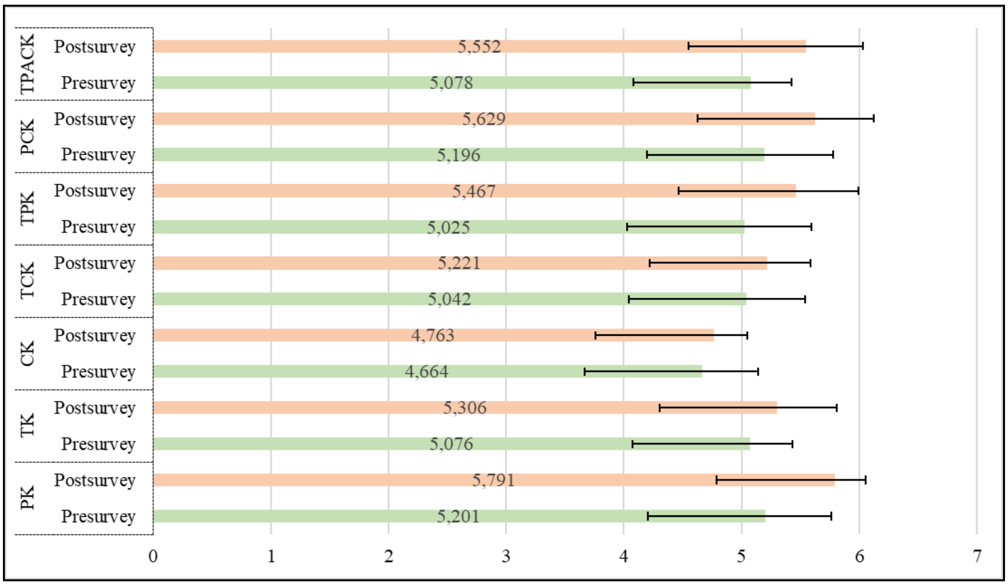

Figure 2. *Means and Error Bars of Data Set for Each TPACK Subdomain in the Pre- And Postsurveys*

Table 3. *Paired-Sample T-Test Results of Preservice Teachers' TPACK*

Statistic	Presurvey		Post survey		Mean difference	95% CI mean differences	t	p-value	d
	Mean	SD	Mean	SD					
PK	5.201	0.560	5.791	0.268	0.589	[0.38, 0.79]	5.842	0.000*	1.34
TK	5.076	0.359	5.306	0.501	0.229	[0.02, 0.42]	2.294	0.025*	0.52
CK	4.664	0.476	4.763	0.285	0.098	[-0.08, 0.27]	1.094	0.278	
TCK	5.042	0.496	5.221	0.368	0.178	[-0.02, 0.37]	1.783	0.079	
TPK	5.025	0.572	5.467	0.525	0.442	[0.24, 0.64]	2.105	0.039*	0.81
PCK	5.196	0.582	5.629	0.493	0.433	[0.18, 0.68]	3.495	0.001*	0.79
TPACK	5.078	0.351	5.552	0.479	0.473	[0.28, 0.66]	4.916	0.000*	1.12

A paired sample t-test was performed to reveal the significant differences in participants' self-reported TPACK domains. Table 3 represents statistically significant differences in the mean differences of PSTs' PK, TPK, and TPACK scores with large effect sizes and TK and PCK scores with medium effect sizes. The mean differences in preservice teachers' CK and TCK scores were not statistically significant.

Research Question 2: Are there any relationships between participants' TPACK and other knowledge bases (TK, PK, CK, TCK, TPK, PCK) at the beginning and end of the final year of the teacher preparation program?

It is desirable to integrate technology, pedagogy, and content into the central component TPACK. This central component has sparked researchers' interest. I examined the relationships between the central component TPACK and other domains (Figure 3).

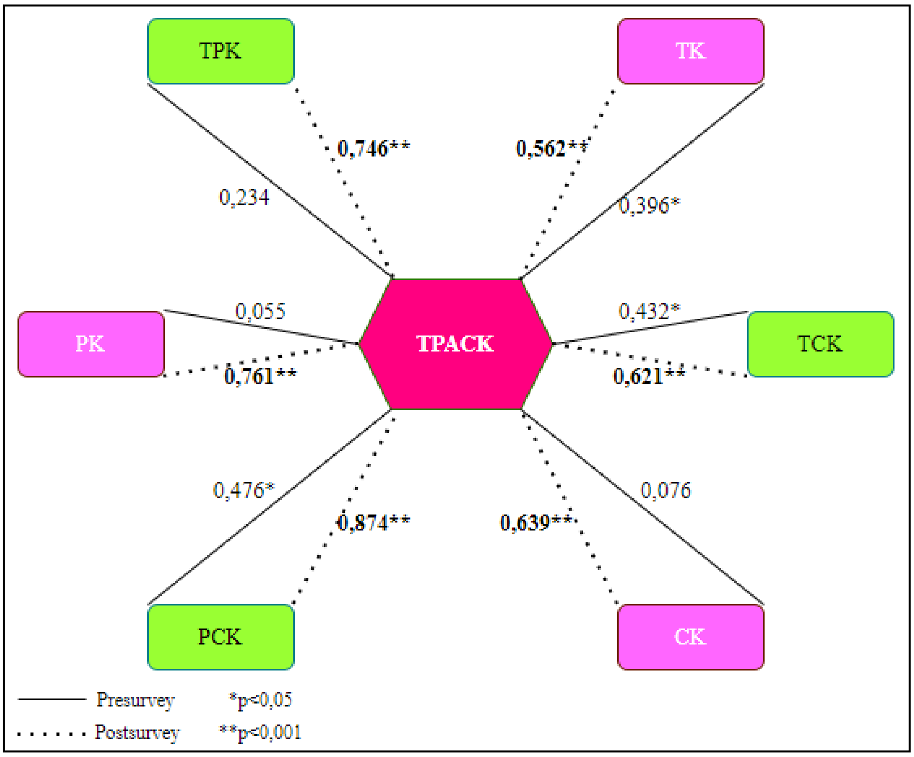

Figure 3. *Correlation Coefficients in the Pre- and Postsurvey*

At the beginning of the final year, only TK, TCK, and PCK had statistically significant and positive relationships with TPACK. Furthermore, the correlation analysis performed at the end of the final year showed statistically significant, high positive correlations with TK ($r = 0.562$, $p < 0.01$), explaining 31.58% of the variance in TPACK; PK ($r = 0.761$, $p < 0.01$), explaining 57.91% of the variance in TPACK; CK ($r = 0.639$, $p < 0.01$) explaining 40.83% of the variance in TPACK; TPK ($r = 0.746$, $p < 0.01$) explaining 55.65% of the variance in TPACK; TCK ($r = 0.621$, $p < 0.01$) explaining 38.56% of the variance in TPACK; and PCK ($r = 0.874$, $p < 0.01$) explaining 76.38% of the variance in TPACK. At the end of the final year, the increase in preservice teachers' TPACK depended on their TK, PK, CK, TPK, TCK, and PCK.

Research Question 3: To what extent do participants' TCK, TPK, and PCK predict their self-reported TPACK at the beginning and end of the final year of the teacher preparation program?

PSTs' TK, PK, and CK exist independently of the others, and then PSTs understand the intersections (TCK, TPK, and PCK) of these knowledge bases (Ritzhaupt et al., 2016). The transformative view assumes that TPACK is influenced by TCK, TPK, and PCK but not directly by TK, PK, and CK (Schmid et al., 2020). Therefore, the last research question deals with the degree to which preservice teachers' TCK, TPK, and PCK contribute to TPACK by performing a multiple linear regression.

Table 4. *Regression Analysis Summary for TCK, TPK, PCK, and TPACK (Presurvey*)

Variable	Unstandardized		Standardized	t	r
	B	Std. Error	β		
TCK	0.320	0.137	0.386*	1.148*	0.253
TPK	0.160	0.167	0.210	0.958	0.162
PCK	0.009	0.122	0.016	0.680	0.134
F (6, 31)			1.665*		
Constant			3.134*		
Durbin-Watson			2.037		
R Square			0.235		
Adjusted R Square			0.249		

*p < 0.05

Table 4 shows that the multiple regression models for presurvey and postsurvey results were significant: F (6,31) = 1.665, p < 0.05, for presurvey and F (6,31) = 5.893, p < 0.001, for postsurvey. PSTs' TCK (t = 1.148, p < 0.05) is the only predictor variable that significantly predicts their TPACK at the beginning of the study. The multiple regression analysis for the presurvey indicated that as mean scores in TCK increased by 1, mean scores for TPACK increased by 0.386.

Table 5. *Regression Analysis Summary for TCK, TPK, PCK, and TPACK (Postsurvey)*

Variable	Unstandardized		Standardized	t	r
	B	Std. Error	β		
TCK	0.361	0.242	0.378*	1.490*	0.348
TPK	0.418	0.174	0.429*	1.268*	0.412
PCK	0.472	0.199	0.486*	2.366*	0.576
F (6,31)			5.893**		
Constant			3.258		
Durbin-Watson			1.813		
R Square			0.657		
Adjusted R Square			0.663		

*p < 0.05; **p < 0.001

Participants' TCK ($t = 1.490$, $p < 0.05$), TPK ($t = 1.268$, $p < 0.05$), and PCK ($t = 2.366$, $p < 0.05$) are significant predictors of TPACK for the postsurvey. The predictor variables accounted for approximately 66% of the criterion variable. Among the three predictor variables, PCK was the strongest predictor of TPACK.

Discussion and Conclusion

This study examined the changes in PSTs' means of TPACK subdomains, the changes in the correlations between the central component TPACK and other subdomains, and the predictions of changes in TPACK by TCK, TPK, and PCK. Participants were in their final year of a teacher preparation program. The self-reported TPACK survey was administered to participants at the beginning and end of the final year. Thirty-eight participants who fully completed both pre- and postsurveys were included in the data analysis. Examining TPACK development within a teacher preparation program may play a critical role in planning to prepare PSTs for a technology-infused workplace (Hofer & Grandgenett, 2012). Therefore, the results of this study may give an insight into which knowledge domains need more support in teacher preparation programs, like the context of this study. The results are discussed in correspondence to each research question.

The Changes in Mean Differences of TPACK Subdomains

PSTs had the highest scores in PCK in the presurvey and PK in the postsurvey. They had the lowest scores in CK in both pre- and postsurveys. The highest mean difference was in PK and the lowest in CK between the pre- and postsurvey results. There were significant differences between pre- and postsurvey results for PK, TK, TPK, PCK, and TPACK, with medium-to-large effect sizes. In CK and TCK, there were no significant differences between pre- and postsurvey results; the PSTs had higher post-scores than pre-scores. The literature includes studies that demonstrate significant differences in TPACK subdomains after attending a technology course (Agyei & Voogt, 2015; Chai et al., 2010; Jin & Harp, 2020; Shinas et al., 2015; Wen & Shinas, 2020), a teaching method course (Açıkgül & Aslaner, 2020), or a lesson study design (Meng & Sam, 2013).

The teacher preparation program coursework in this study supported PSTs' PK and knowledge domains related to PK. Similarly, Valtonen et al. (2019) and Thohir et al. (2021) found that positive gains occurred mainly in areas related to PK. Besides, the largest effect sizes from t-tests were in PK and TPACK, respectively. To sum up, the teacher preparation program's final year supported PSTs' PK and other knowledge domains involved with pedagogical thinking. The student teaching in the final year may have made participants focus more on pedagogical thinking than technological domains. Teacher educators in the context of this study should model content-specific technologies and allow PSTs to teach with technology and reflect on their attempts (Wang et al., 2018; Wen & Shinas, 2020). This result may imply that the context of this study needs to give PSTs more opportunities to engage with content-specific technologies. It is unexpected that the results revealed no significant differences in TCK as participants took a mathematics-related technology course in the first semester of their final year. TCK may be challenging for teacher education (Graham et al., 2009; Valtonen et al., 2019).

The Changes in Relationships Between TPACK Subdomains

TK, TCK, and PCK had moderately significant positive correlations with TPACK in the presurvey. This result indicated that increasing PSTs' TK, TCK, and PCK also increased TPACK at the beginning of the final year. The relationship between the central component, TPACK, and other knowledge domains changed over time. At the end of the final year, the correlation analysis revealed that all subdomains had significantly strong positive relationships with the central component, TPACK. Similarly, numerous studies have shown that the relationship between TPACK and other knowledge domains becomes more significant and stronger after some time (Agyei & Keengwe, 2014; Miguel-Revilla et al., 2020; Thohir et al., 2021).

All correlation coefficients were large. The strongest relationship occurred between TPACK and PCK, PK, and TPK, respectively. This result supports the implication that the contribution of the teacher education program to TPACK development was pedagogy-driven. The weakest relationship was between TPACK and TK. The change in relationships between TPACK and other knowledge domains shows that PSTs had a more integrative view of TPACK at the end of the teacher preparation program. It is possible to say that participants considered TPACK to see beyond technology, pedagogy, and content as individual domains (Koehler & Mishra, 2008).

The data analysis indicated that TCK was the only predictor of TPACK among three variables (TCK, TPK, and PCK) in the presurvey. TCK accounted for 6% of the variance in TPACK. The predictive relationship changed within the context of the final year. A stronger predictive model was found in the postsurvey. The postsurvey regression analysis indicated that the intersections of the primary knowledge domains (TK, PK, and CK) were predictors of TPACK. The model, including TCK, TPK, and PCK, significantly accounted for 66% of the variation in PSTs' TPACK. PCK made the largest significant contribution to TPACK development. This result suggests that participants of this study should learn how to teach mathematics comprehensibly to others. Researchers proposed that teachers with weaker pedagogical skills may fail to connect technology, pedagogy, and content even if they have technical skills (Chai et al., 2010). Similarly, PK and domains involving PK were significant predictors of TPACK in many studies (Chai et al., 2010; Shinas et al., 2015). Comparing the regression models from the beginning and end of the final year, TCK was the only significant predictor in both administrations.

Implications

Researchers have suggested that longitudinal studies promote PSTs' TPACK development (Wen & Shinas, 2020). This study investigated the changes in PSTs' self-perceptions of TPACK subdomains in their natural setting of the final year in the teacher preparation program throughout two semesters. The results indicated that the PSTs' perceptions of PK, TK, TPK, TCK, and TPACK had positive gains. However, the standard deviation in TK and TPACK increased, demonstrating the increasing spread of participants. This result implies that the participants laid on a broader range at the end of their final year. Therefore, providing more opportunities for PSTs to develop their TPACK becomes more important to sustain equity in qualifications. The teacher preparation program enhanced PSTs' integrative view of TPACK as TPACK had strong relationships with other knowledge domains at the end of the program. TCK was the only predictor of TPACK in the presurvey, but TCK did not indicate a significant gain at the end of the program. Given the predictive power of TCK at the beginning of the final year and the non-existence of an increase in TCK, it is worth noting that PSTs need more support in realizing the effect of technology and mathematics on each other. Teacher educators should focus on demonstrating how technology improves mathematics teaching and learning and how mathematics promotes technology use. Improving TCK is crucial since the lack of experience in learning mathematics with technology is one of the main barriers to technology integration for mathematics teaching (Niess, 2008).

The results of this study point out that teacher preparation programs should improve the technological aspect of their training. The contribution of the teacher preparation program was mainly pedagogy-driven. Given the necessity of digital competencies to design and perform digital-based instruction in the technology-infused era, teacher preparation programs like the context of this study need to focus more on how to make PSTs recognize the connections between technology and content-area and teaching-learning. This may be possible by using technology modeling from teacher educators and providing opportunities to plan and teach technology-based lessons, reflect on these attempts, and place PSTs in classrooms where teachers use technology effectively (Mouza et al., 2014; Wang et al., 2018). Content-centric approaches will undoubtedly advance the content of teacher preparation programs to support PSTs in developing their skills in teaching with technology.

Limitations

This study is limited to a self-report survey and a small sample size. In longitudinal studies, data collection from a larger sample is often challenging (Hofer & Grandgenett, 2012). Only one cohort enrolled in the final year, and all PSTs in the cohort group were not included in the data analysis because of sample loss and missing data. These results may represent participants and contexts like this study, but the generalizability of these results to more diverse and larger populations is limited. The second limitation is using only one kind of measurement, a self-reported measure. Self-reported data may demonstrate to what extent PSTs feel confident in TPACK subdomains (Harris et al., 2010). The consistency of the self-reported measures with actual behaviors depends on the respondents' ability to appraise their own knowledge accurately (Abbitt, 2011). The results may predict participants' actual teaching behaviors but do not accurately reveal what participants know and do in class (Agyei & Keengwe, 2014). Additionally, it is necessary to use different measurement tools such as performance assessments and interviews to assess PSTs' preparation to teach with technology (Wen & Shinas, 2020). Further research may investigate the TPACK development with various measurement tools and a larger sample size over a long time, like in this study.

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References

Abbitt, J. T. (2011). An investigation of the relationship between self-efficacy beliefs about technology integration and technological pedagogical content knowledge (TPACK) among preservice teachers. *Journal of Digital Learning in Teacher Education, 27*(4), 134–143.

Açıkgül, K., & Aslaner, R. (2020). Effects of GeoGebra supported micro-teaching applications and technological pedagogical content knowledge (TPACK) game practices on the TPACK levels of prospective teachers. *Education and Information Technologies, 25*(3), 2023–2047.

Agyei, D. D., & Keengwe, J. (2014). Using technology pedagogical content knowledge development to enhance learning outcomes. *Education and Information Technologies*, *19*(1), 155–171.

Agyei, D. D., & Voogt, J. M. (2015). Preservice teachers' TPACK competencies for spreadsheet integration: Insights from a mathematics-specific instructional technology course. *Technology, Pedagogy and Education, 24*(5), 605–625.

Akkoç, H. (2011). Investigating the development of prospective mathematics teachers' technological pedagogical content knowledge. *Research in Mathematics Education*, *13*(1), 75–76.

Almanthari, A., Maulina, S., & Bruce, S. (2020). Secondary school mathematics teachers' views on E-learning implementation barriers during the COVID-19 pandemic: The case of Indonesia. *Eurasia Journal of Mathematics, Science and Technology Education*, *16*(7), 1–9.

Angeli, C., Valanides, N., & Christodoulou, A. (2016). Theoretical considerations of technological pedagogical content knowledge. In M. C. Herring, M. J. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPACK) for educators* (2nd ed., pp. 11–32). Routledge.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191–215.

Bourke, R. (2014). Self-assessment in professional programmes within tertiary institutions. *Teaching in Higher Education, 19*(8), 908–918.

Buss, R. R., Foulger, T. S., Wetzel, K., & Lindsey, L. (2018). Preparing teachers to integrate technology into K–12 instruction II: Examining the effects of technology-infused methods courses and student teaching. *Journal of Digital Learning in Teacher Education*, *34*(3), 134–150.

Chai, C. S., Koh, J. H. L., & Tsai, C.-C. (2010). Facilitating preservice teachers' development of technological, pedagogical, and content knowledge (TPACK). *Educational Technology & Society*, *13*(4), 63–73.

Cohen, J. C. (1988). *Statistical power analysis for the behavioral sciences* (2nd Ed.). Lawrence Earlbaum Associates.

Cohen, L., Manion, L. & Morrison, K. (2007). *Research methods in education* (6th Ed.). Taylor & Francis.

Cox, S., & Graham, C. R. (2009). Using an elaborated model of the TPACK framework to analyze and depict teacher knowledge. *TechTrends, 53*(5), 60–69.

Creswell, J. W. (2012). Educational research: Planning, conducting, and evaluating quantitative and qualitative research. Pearson Education.

Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of Research on Technology in Education, 42*(3), 255–284.

Field, A. (2013). Discovering statistics using IBM SPSS statistics (4th ed.). Sage.

Figg, C., & Jaipal, K. (2009, March). Unpacking TPACK: TPK characteristics supporting successful implementation. In *Society for Information Technology & Teacher Education International Conference* (pp. 4069–4073). Association for the Advancement of Computing in Education (AACE).

Figg, C., & Jaipal, K. (2012, March). TPACK-in-practice: Developing 21st-century teacher knowledge. In *Society for Information Technology & Teacher Education International Conference* (pp. 4683–4689). Association for the Advancement of Computing in Education (AACE).

Fives, H., & Buehl, M. M. (2008). What do teachers believe? Developing a framework for examining beliefs about teachers' knowledge and ability. *Contemporary Educational Psychology*, *33*(2), 134–176.

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to Design and Evaluate Research in Education* (8th ed.). McGraw-Hill.

Graham, R. C., Burgoyne, N., Cantrell, P., Smith, L., St Clair, L., & Harris, R. (2009). Measuring the TPACK confidence of in-service science teachers. *TechTrends, 53*(5), 70–79.

Grandgenett, N. F. (2008). Perhaps a matter of imagination: TPCK in mathematics education. In AACTE Committee on Innovation and Technology (Ed.), *The handbook of technological pedagogical content knowledge (TPCK) for educators*. American Association of Colleges of Teacher Education/Routledge.

Harris, J., Grandgenett, N., & Hofer, M. (2010). Testing a TPACK-based technology integration assessment rubric. In C. Crawford, D. A. Willis, R. Carlsen, I. Gibson, K. McFerrin, J. Price & R. Weber (Eds.), *Proceedings of the Society for Information Technology & Teacher Education International Conference 2010* (pp. 3833–3840). Association for the Advancement of Computing in Education (AACE).

Hofer, M., & Grandgenett, N. (2012). TPACK development in teacher education: A longitudinal study of preservice teachers in a secondary MA Ed. program. *Journal of Research on Technology in Education, 45*(1), 83–106.

Jin, Y., & Harp, C. (2020). Examining preservice teachers' TPACK, attitudes, self-efficacy, and perceptions of teamwork in a stand-alone educational technology course using flipped classroom or flipped team-based learning pedagogies. *Journal of Digital Learning in Teacher Education*, *36*(3), 166–184.

Joshi, A., Kale, S., Chandel, S., & Pal, D. K. (2015). Likert scale: Explored and explained. *Current Journal of Applied Science and Technology*, 396–403.

Kafyulilo, A., Fisser, P., Pieters, J., & Voogt, J. (2015). ICT use in science and mathematics teacher education in Tanzania: Developing technological pedagogical content knowledge. *Australasian Journal of Educational Technology*, *31*(4), 381–399.

Kartal, T., Kartal, B., & Uluay, G. (2016). Technological pedagogical content knowledge self-assessment scale (TPACK-SAS) for preservice teachers: Development, validity and reliability. *International Journal of Eurasia Social Sciences, 7*(23),1–36.

Kay, R. H. (2006). Evaluating strategies used to incorporate technology into preservice education: A review of the literature. *Journal of Research on Technology in Education*, *38*(4), 383–408.

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

Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy and technology. *Computers & Education, 49*(3), 740–762.

Koh, J. H., & Divaharan, H. (2011). Developing preservice teachers' technology integration expertise through the TPACK-developing instructional model. *Journal of Educational Computing Research, 44*(1), 35–58.

König, J., Jäger-Biela, D. J., & Glutsch, N. (2020). Adapting to online teaching during COVID-19 school closure: Teacher education and teacher competence effects among early career teachers in Germany. *European Journal of Teacher Education*, *43*(4), 608–622.

Lawless, K. A., & Pellegrino, J. W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research*, *77*(4), 575–614.

Mainali, B. R., & Key, M. B. (2012). Using dynamic geometry software GeoGebra in developing countries: A case study of impressions of mathematics teachers in Nepal. *International Journal for Mathematics Teaching and Learning, 12*, 1–21.

Meng, C. C., & Sam, L. C. (2013). Developing preservice teachers' technological pedagogical content knowledge for teaching mathematics with the Geometer's Sketchpad through lesson study. *Journal of Education and Learning, 2*(1), 1–8.

Miguel-Revilla, D., Martínez-Ferreira, J. M., & Sánchez-Agustí, M. (2020). Assessing the digital competence of educators in social studies: An analysis in initial teacher training using the TPACK-21 model. *Australasian Journal of Educational Technology*, *36*(2), 1–12.

Mishra, P. (2019). Considering contextual knowledge: The TPACK diagram gets an upgrade. *Journal of Digital Learning in Teacher Education, 35*(2), 76–78.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A new framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

Mouza, C., Karchmer-Klein, R., Nandakumar, R., Ozden, S. Y., & Hu, L. (2014). Investigating the impact of an integrated approach to the development of preservice teachers' technological pedagogical content knowledge (TPACK). *Computers & Education, 71*, 206–221.

Mudzimiri, R. (2010). Developing TPACK in preservice secondary mathematics teachers through integration of methods and modelling courses: Results of a pilot study. In D. Gibson & B. Dodge (Eds.), *Proceedings of society for information technology & teacher education international conference* (pp. 3485–3490). AACE.

National Council of Teachers of Mathematics. (2014). *Principles to actions: Ensuring mathematics success for all.* National Council of Teachers of Mathematics.

Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: Developing a technology pedagogical content knowledge. *Teaching and Teacher Education, 21*(5), 509–523.

Niess, M. L. (2008). Mathematics teachers developing technology, pedagogy, and content knowledge (TPACK). In C. Crawford, et al. (Eds.), *Proceedings of Society for Information Technology and Teacher Education International Conference 2007*. AACE.

Njiku, J., Mutarutinya, V., & Maniraho, J. F. (2021). Building mathematics teachers' TPACK through collaborative lesson design activities. *Contemporary Educational Technology, 13*(2), 1–14. https://doi.org/10.30935/CEDTECH/9686

Ozgun-Koca, S. A., Meagher, M., & Edwards, M. T. (2010). Preservice teachers' emerging TPACK in a technology-rich methods class. *The Mathematics Educator, 19*(2), 10–20.

Panadero, E., Alonso-Tapia, J., & Huertas, J. A. (2012). Rubrics and self-assessment scripts effects on self-regulation, learning and self-efficacy in secondary education. *Learning and Individual Differences, 22*(6), 806–813.

Panadero, E., Alonso-Tapia, J., & Reche, E. (2013). Rubrics vs. self-assessment scripts effect on self-regulation, performance and self-efficacy in preservice teachers. *Studies in Educational Evaluation*, *39*(3), 125–132.

Pierson, M. (2008, March). Teacher candidates reflect together on their own development of TPCK: Edited teaching videos as data for inquiry. In *Society for Information Technology & Teacher Education International Conference* (pp. 5305–5309). AACE.

Polly, D. (2014). Deepening preservice teachers' knowledge of technology, pedagogy, and content (TPACK) in an elementary school mathematics methods course. *Journal of Computers in Mathematics and Science Teaching*, *33*(2), 233–250.

Polly, D., & Orrill, C. H. (2012). Developing technological pedagogical and content knowledge (TPACK) through professional development focused on technology rich mathematics tasks. *The Meridian*, 15 [online journal]. http://ced.ncsu.edu/meridian/index.php/meridian/article/view/44/43

Polly, D., Mims, C., Shepherd, C. E., & Inan, F. (2010). Evidence of impact: Transforming teacher education with preparing tomorrow's teachers to teach with technology (PT3) grants. *Teaching and Teacher Education, 26*(4), 863–870.

Ritzhaupt, A. D., Huggins-Manley, A. C., Ruggles, K., & Wilson, M. (2016). Validation of the survey of preservice teachers' knowledge of teaching and technology: A multi-institutional sample. *Journal of Digital Learning in Teacher Education*, *32*(1), 26–37.

Schmid, M., Brianza, E., & Petko, D. (2020). Developing a short assessment instrument for technological pedagogical content knowledge (TPACK.xs) and comparing the factor structure of an integrative and a transformative model. *Computers & Education, 157*, 1–12.

Shadish, W., Cook, T., & Campbell, D. (2002). Statistical conclusions: Validity and internal validity. In *Experimental and quasi experimental designs for generalized causal inference*. Cengage Learning.

Shinas, V. H., Karchmer-Klein, R., Mouza, C., Yilmaz-Ozden, S., & J. Glutting, J. (2015). Analyzing preservice teachers' Technological Pedagogical Content Knowledge development in the context of a multidimensional teacher preparation program. *Journal of Digital Learning in Teacher Education*, *31*(2), 47–55.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–23.

Thohir, M. A., Yuliati, L., Ahdhianto, E., Untari, E., & Yanti, F. A. (2021). Exploring the relationship between personality traits and TPACK-web of pre-service teachers. *Contemporary Educational Technology*, *13*(4), ep322, https://doi.org/10.30935/cedtech/11128

Valtonen, T., Sointu, E., Kukkonen, J., Mäkitalo, K., Hoang, N., Häkkinen, P., Järvelä, S., Näykki, P., Virtanen, A., Pöntinen, S., Kostiainen, E., & Tondeur, J. (2019). Examining preservice teachers' Technological Pedagogical Content Knowledge as evolving knowledge domains: A longitudinal approach. *Journal of Computer Assisted Learning*, *35*(4), 491–502.

Wang, W., Schmidt-Crawford, D., & Jin, Y. (2018). Preservice teachers' TPACK development: A review of literature. *Journal of Digital Learning in Teacher Education*, *34*(4), 234–258.

Wen, H., & Shinas, V. H. (2020). Using a multidimensional approach to examine TPACK among teacher candidates. *Journal of Digital Learning in Teacher Education*, *37*(1), 1–18.

Young, J. R., Young, J., Hamilton, C., & Pratt, S. S. (2019). Evaluating the effects of professional development on urban mathematics teachers TPACK using confidence intervals. *REDIMAT*, *8*(3), 312–338.

Zelkowski, J., Gleason, J., Cox, D. C., & Bismarck, S. (2013). Developing and validating a reliable TPACK instrument for secondary mathematics preservice teachers. *Journal of Research on Technology in Education, 46*(2), 173–206.