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An exploratory study of pre-service teachers' perceptions of technological pedagogical content knowledge of digital games

Yu-Chun Kuo [1] * and Yu-Tung Kuo [2]

*Correspondence:
yuchun100@gmail.com;
kuo@rowan.edu
Department of Science, Technology, Engineering, Art, and Math Education,
Rowan University,
201 Mullica Hill Rd., Glassboro, NJ 08028, United States
Full list of author information is available at the end of the article

Abstract

This study investigated pre-service teachers' perceptions of technological pedagogical content knowledge of digital games (TPACK-G), the correlation of TPACK-G constructs, and the relation of TPACK-G to personal factors and levels of motivation and self-efficacy. Participants were 96 pre-service teachers from a university in the northeastern United States. Data were collected using online surveys. Quantitative approaches were performed to analyze the data. Results indicated that game content knowledge (GCK) and game pedagogical knowledge (GPK) significantly predicted pre-service teachers' game pedagogical content knowledge (GPCK), with GPK being the strongest predictor. Pre-service teachers with high levels of motivation or self-efficacy for digital game integration had significantly better TPACK-G than those with low levels. Personal factors, including gender and prior experiences with digital games, were found to be influential to pre-service teachers' TPACK-G. This study adds to the understanding of the application of the TPACK model in the context of digital game use for pre-service teachers.

Keywords: Digital games, Game-based learning, TPACK-G, Motivation, Self-efficacy, Pre-service teachers

Introduction

In recent years, digital games have gradually gained much of the attention from educators or teachers in both higher and K-12 education (Acquah & Katz, 2020; Lengyel, 2020; McLaren et al., 2022). It is believed that digital games have the potential to enhance students' meaningful learning experiences profoundly, and to help foster 21st century skills (e.g., critical thinking, communicating, problem solving, etc.) and other essential skills required for future careers (Acquah & Katz, 2020; An, 2018; An & Cao, 2017; Hsu et al.,

2017; Giang & Cuong, 2021; Kuo, Kuo, & Whittinghill, 2022; Sun et al., 2022). Despite the increasing interests of using digital games in the classroom, many teachers may not fully recognize the educational potential of digital games, or encounter difficulties or problems when incorporating digital games into teaching, due to limited experiences or unfamiliarity with digital games (Hsu et al., 2017; Kaimara et al., 2021). Teacher education programs could serve as a bridge to minimize the gap by integrating digital games or digital game-based learning into the curriculum, which echoes the call from Blume (2020) and Takeuchi and Vaala (2014) for the necessity to offer pre-service teachers formal training on digital game interaction and the strategies to integrate digital games into instruction.

The model of technological pedagogical content knowledge (TPACK) has been regarded as a guideline to the design of curricular experiences that successfully instill pre-service teachers with knowledge and skills to integrate technology into teaching (Jung & Ottenbreit-Leftwich, 2020; Redmond & Peled, 2019; Schmid et al., 2021; Tunjera & Chigona, 2020). Although there are many TPACK studies, there is a lack of guidelines targeting TPACK in the context of digital games (Hsu et al., 2013). Therefore, Hsu et al. (2013), building on TPACK, proposed the framework of technological pedagogical content knowledge for digital games (TPACK-G) for evaluating and guiding the integration of digital games, pedagogy, and content into teaching. Hsu et al. (2013, 2017) mainly examined TPACK-G among in-service teachers. Our study proposed to apply TPACK-G for pre-service teachers.

Previous research indicated the importance of understanding the relationships and developmental paths among TPACK constructs for teachers' TPACK development processes (Hsu et al., 2015; Santika et al., 2021). For TPACK-G, there is limited research addressing the relationships of TPACK-G constructs (Hsu et al., 2017), and a lack of research on TPACK-G in the context of pre-service teachers. In addition, motivation and self-efficacy are deemed as critical to teachers' adoption of technology in educational contexts (Barton & Dexter, 2020; Cengiz, 2015; Ertmer & Ottenbreit-Leftwich, 2010). Teachers' interests and confidence in using digital games play a crucial role in determining their intention to adopt digital games in teaching (An, 2018; Hsu et al., 2017). Personal factors such as gender, age, and experiences of digital game playing, may also influence teachers' use of digital games in teaching (Hsu et al., 2017). There is a dearth of research examining how motivation, self-efficacy, and personal factors relate to TPACK-G. Therefore, the purpose of this study is to explore pre-service teachers' perceptions of TPACK-G, specifically on the relationships of TPACK-G constructs and the relation of TPACK-G to motivation, self-efficacy, and personal factors.

Literature review

Technological pedagogical content knowledge (TPACK)

Technological pedagogical content knowledge (TPACK) serves as the theoretical framework of this study. The TPACK framework addresses the nature of knowledge for teachers to integrate technology into teaching (Koehler & Mishra, 2009; Koehler et al., 2013; Mishra & Koehler, 2006). The TPACK framework builds on Shulman's (1986) conception of pedagogical content knowledge (PCK) by adding the knowledge of technology (TK) as an integral part of pedagogical knowledge (PK) and content knowledge (CK). The ultimate goal of TPACK is to provide teachers or educators with guidelines to effectively and successfully integrate the use of information and communication technology (ICT) into various forms of teaching and learning, in accordance with the adoption of appropriate pedagogical strategies (Koehler & Mishra, 2009; Koehler et al., 2013; Mishra & Koehler, 2006).

The TPACK framework begins with three main components, including content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK) (Koehler & Mishra, 2009; Mishra & Koehler, 2006). Instead of treating these three components of knowledge as an isolated body, the TPACK framework places an emphasis on the importance of complex, dynamic, and multifaceted relationships among these three types of knowledge (i.e., CK, PK, and TK) (Mishra & Koehler, 2006). The complex interplay of content knowledge, pedagogical knowledge, and technological knowledge leads to four intermediate forms of knowledge, including pedagogical content knowledge (PCK), technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK) (Koehler & Mishra, 2009; Koehler et al., 2013; Mishra & Koehler, 2006).

PCK indicates applying appropriate teaching strategies or methods to represent a specific subject content and make it more comprehensible to learners. TCK denotes the knowledge of using appropriate technology to create various representations for a subject content. TPK means the knowledge of the existence and capabilities of various forms of technology when they are used to implement particular teaching methods or strategies, and understanding that the use of technology may alter the way teachers teach. TPACK is a contextualized synthesis of all six forms of knowledge (i.e., CK, PK, TK, PCK, TCK, and TPK), referring to the understanding of the connections and interaction between and among content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK) to teach effectively.

TPACK for pre-service teachers

TPACK is contextually bound and referred as a situated form of knowledge (Rosenberg & Koehler, 2015). In teacher education, the TPACK framework provides a basis for teacher educators to prepare teacher candidates for the development of their competencies to effectively use and integrate ICT into future classroom teaching (Lu & Wang, 2021). Since its inception, the TPACK research for pre-service teachers has been widely conducted in different settings (e.g., classrooms, teaching practices, field placements, grade levels, etc.) and across subject areas (e.g., math, science, language learning, etc.) (Dewi et al., 2021). The main topics for pre-service teachers' TPACK include the measurement and development of pre-service teachers' TPACK abilities, barriers or challenges for developing TPACK, scaffolding or modeling for TPACK development, and factors (e.g., self-confidence, teaching experiences, student background, technology use, etc.) associated with TPACK (Dewi et al., 2021; Lu & Wang, 2021; Schmid et al., 2021; Tondeur et al., 2020; Wang et al., 2018). Most of the TPACK studies on pre-service teacher measure the technology-related components of TPACK based on the combined use of technology that covers a wide range of technology tools, rather than a specific type of technology (Schmid et al., 2021). Limited research has investigated pre-service teachers' TPACK in the context specific to the use of digital games (i.e., TPACK-G) (Hsu et al., 2017).

Technological pedagogical content knowledge of digital games (TPACK-G) and the relationships of TPACK-G constructs

Hsu et al. (2013) proposed a framework of technological pedagogical content knowledge for digital games (TPACK-G), based on the TPACK model developed by Mishra and Koehler (2009). The TPACK-G framework includes four elements: game knowledge (GK), game content knowledge (GCK), game pedagogical knowledge (GPK), and game pedagogical content knowledge (GPCK) (Hsu et al., 2013). Game knowledge (GK) refers to the knowledge about the general usage of computer or digital games. Game content knowledge (GCK) indicates the knowledge about how to use games to represent a subject content without considering the implementation of teaching methods or strategies. Game pedagogical knowledge (GPK) is the knowledge about the use of games in alignment with the implementation of various pedagogical approaches, without taking into consideration of a specific content knowledge. Game pedagogical content knowledge (GPCK) denotes the knowledge of using appropriate games to implement teaching methods or strategies for any specific content knowledge.

The relationships of TPACK constructs have been manifested in some of the quantitative studies that examined the influences of TK, PK, CK, and intermediary factors (i.e., PCK,

TCK, and TPK) on TPACK (Chai et al., 2010; Chai et al., 2012; Koh et al., 2013; Pamuk et al., 2015; Santika et al., 2021). Underpinned by the TPACK framework, the importance of investigating the relationships of TPACK-G constructs arises. Hsu et al. (2013) indicated that possessing adequate GK and GPK is fundamental to the development of GPCK, based on their study about preschool teachers' technological pedagogical content knowledge of educational games. In another study conducted by Hsu et al. (2017) on elementary and middle school teachers' perceptions of technological pedagogical content knowledge for games, GK, GCK, GPK, and GPCK were found to be positively correlated with each other. GK, GCK and GPK were all significant predictors of GPCK. Compared to other TPACK-G constructs, GPK was the most critical element in developing teachers' GPCK.

Motivation and self-efficacy in relation to TPACK-G

Motivation refers to the process through which an individual is willing to exert and sustain his or her effort for a goal-oriented behavior (Kim, 2011; Schunk, 1990). Levels of motivation in teachers have been considered important to technology integration or the innovative use of technology (Kim, 2011; Raman et al., 2022; Sang et al., 2011). Motivational problems (e.g., low interests or value) likely lead to deficits in technology integration (Efe & Baysal, 2017; Kim, 2011; Venkatesh et al., 2002). Teachers with high levels of motivation tend to make the most of use of technology tools in their classroom teaching, and continuously try out new tools or applications to be excellent in their instruction (Efe & Baysal, 2017; Habibi et al., 2021). Conversely, unmotivated teachers exhibit low aspirations or interests for integrating technology or continuous usage of technology in teaching (Sang et al, 2011). Teachers' motivation to adopt technology was claimed to be related to their levels of TPACK competencies (Hsu et al., 2017), although with limited research verifying such relationships. Hsu et al. (2017) found that teachers' motivation to adopt digital games was positively correlated with TPACK-G constructs.

Self-efficacy that refers to an individual's judgement of his or her ability to accomplish a required task (Bandura, 1977), is another important factor in technology integration for teachers (Barton & Dexter, 2020; Ertmer & Ottenbreit-Leftwich, 2010). Self-efficacy for technology integration, focusing on one's confidence in incorporating technology into teaching, is critical to determining teachers' actual use of technology in the classroom (Barton & Dexter, 2020; Ertmer & Ottenbreit-Leftwich, 2010; Kuo & Kuo, 2020; Kuo, Kuo, & Abi-El-Mona, 2022; Lee & Lee, 2014). It significantly influences pre-service teachers' decision of adopting technology in teaching practices or future teaching (Song, 2018; Wang et al., 2004). Pre-service or novice teachers with high levels of technology integration self-efficacy are likely to succeed in technology-integrated tasks (Backfisch et al., 2020; Celik & Yesilyurt, 2013; Lee & Lee, 2014). Previous research suggests that increasing teachers' competency levels of TPACK would lead to better self-efficacy beliefs

about technology integration (Abbitt, 2011; Durak, 2019). Some studies found a positive relationship between TPACK constructs and self-efficacy for technology integration (Abbitt, 2011; Dong et al., 2020; Keser et al., 2015; Semiz & Ince, 2012). Hsu et al. (2017) adopted this assumption in their research on teachers' TPACK-G, and found positive correlations between TPACK-G constructs and teachers' confidence in adopting digital games in teaching.

Personal factors and TPACK-G

Personal factors (e.g., individual characteristics) may play an important role in TPACK (Schmid et al., 2021). In terms of gender, several studies indicated that males appear to have significantly better TK, TCK, TPK, or TPCK than females (Ergen et al., 2019; Yusuf et al., 2021). Teachers' experience of using technology is a critical factor for technology adoption; however, limited research has investigated how this factor is related to TPACK (Lu & Wang, 2021; Schmid et al., 2021). Lu and Wang (2021) found that pre-service teachers' experience of using technology had an influence on some components of TPACK (Lu & Wang, 2021). As for the factor of age, according to Schmid et al. (2021), age has been considered as relevant for TPACK. With the limited research investigating the relation of personal factors to TPACK-G (Hsu et al., 2013; Hsu et al., 2017), we explored how three personal factors, including gender, age, and years of experiences of playing digital games, had an influence on TPACK-G in this study.

Research questions

1. Do pre-service teachers' GK, GCK, GPK, and GPCK differ in terms of gender, age, and years of experience of playing digital games?
2. Do pre-service teachers' GK, GCK, GPK, and GPCK differ in terms of their motivation to use digital games for future teaching?
3. Do pre-service teachers' GK, GCK, GPK, and GPCK differ in terms of their self-efficacy of integrating digital games?
4. What are the relationships of pre-service teachers' GK, GCK, GPK, and GPCK?
5. Do pre-service teachers' GK, GCK, and GPK predict GPCK?

Method

Participants

Participants were 96 students enrolled in the Educational Technology courses from a northeastern university in the United States (see Table 1). The undergraduate-level courses were face-to-face and taught by the same instructor. The undergraduate students were pre-service teachers, with the majority of them in their sophomore (37.5%) or junior (46.9%)

Table 1 Background information of pre-service teachers

Characteristic	*n*	*%*
Gender		
Male	12	12.5
Female	84	87.5
Age		
18-19	28	29.2
20-21	43	44.8
22 and above	25	26.0
Grade level		
Freshman	6	6.3
Sophomore	36	37.5
Junior	45	46.9
Senior	9	9.4
Years of playing digital games		
1-5	11	11.6
6-10	41	43.2
11-15	34	35.8
16-20	9	9.5

year. There were much more female students (87.5%) than male students (12.5%). Most of them aged between 18-21 years (74%). All of the students had the experience of playing digital games, with the majority of them playing digital games for 6-10 (43.2%) or 11-15 (35.8%) years. Few students had played digital games for about 1-5 years (11.6%) or more than 15 years (9.5%).

Data collection

The study was conducted using an online survey. The online pre- and post-surveys were provided to students at the beginning and the end of the digital game learning project. The study was approved by the university's Institutional Review Board (IRB), and informed consent forms were obtained from the students who participated in the survey. The survey questionnaire consisted of seven sections: student background information, motivation, self-efficacy, game knowledge (GK), game content knowledge (GCK), game pedagogical knowledge (GPK), and game pedagogical content knowledge (GPCK) (see Table 2). Student background information included gender, age, grade level, and the number of years that students had played digital games.

Table 2 Instruments

Scales	Number of items	Range	Cronbach's alpha
Motivation	4	1-7	0.94
Self-efficacy	16	1-5	0.96
GK	4	1-5	0.93
GCK	4	1-5	0.95
GPK	4	1-5	0.93
GPCK	4	1-5	0.91

The TPACK-G instrument, originally developed by Hsu et al. (2017), was adopted to measure pre-service teachers' confidence in GK, GCK, GPK, and GPCK. The motivation scale, developed by Shroff and Keyes (2017), was adapted to measure pre-service teachers' perceived interest in pursuing new knowledge and getting motivated to engage in various learning activities or tasks with the use of digital games. The digital game integration self-efficacy scale was adapted from the instrument developed by Wang et al. (2004) that measured pre-service teachers' technology integration self-efficacy. Both of the TPACK-G instrument and digital game integration self-efficacy scale are a 5-point Likert scale. The motivation scale is a 7-point Likert scale. The Cronbach's coefficient alpha values calculated based on the sample of this study were high: GK (0.93), GCK (0.95), GPK (0.93), GPCK (0.91), motivation (0.94), and digital game integration self-efficacy (0.96) (see Table 2).

Procedure

Pre-service teachers who attended the Educational Technology classes were asked to participate in a digital game learning project that took per-service teachers about five weeks to complete. This project required pre-service teachers to explore existing digital games that would be beneficial to student learning in the subject area that they will teach in the future, analyze the selected digital games, and create a lesson plan that integrates the use of digital games. Prior to the beginning of the project, the instructor provided an overview of the project and relevant resources (i.e., project procedures, useful websites for digital games, lesson plan templates, etc.) for digital game search and lesson plan development. At the end of the project, pre-service teachers were required to present to the class about their selected digital games and developed lesson plans that integrated the use of digital games. Feedback from the instructor and peers was provided to help pre-service teachers refine their lesson plan.

Data analysis

Data were analyzed using quantitative approaches. Quantitative approaches included descriptive analyses, t-Tests, ANOVAs, and correlation and regression analyses. SPSS 20 was used for data analyses. Normality of the data and homogeneity of variance were examined. Multicollinearity test was performed for the regression analysis.

Results

RQ1: Do pre-service teachers' GK, GCK, GPK, and GPCK differ in terms of gender, age, and years of experience of playing digital games?

T-Test analyses in Table 3 show that gender had a significant influence on GCK ($t = 2.01$, $p < .05$) and GPCK ($t = 1.99$, $p < .05$), but not on GK ($t = 1.03$, $p > .05$) and GPK ($t = 1.93$, $p > .05$). Female pre-service teachers had significant higher average scores on GCK ($M_{female} = 4.55$; $M_{male} = 4.21$) and GPCK ($M_{female} = 4.50$; $M_{male} = 4.17$) than male pre-service teachers. According to ANOVA analyses, age did not significantly influence pre-service teachers' GK, GCK, GPK, and GPCK (see Table 4). Table 5 shows that pre-service teachers' experience of playing digital games significantly influenced their GK ($F = 3.96$, $p < .05$), GCK ($F = 3.96$, $p < .05$), GPK ($F = 3.96$, $p < .05$), and GPCK ($F = 3.96$, $p < .05$). Post hoc tests showed that pre-service teachers who had played digital games for 6-10 years had significantly higher averages on GK, GCK, GPK, and GPCK than those who had played digital games for 1-5 years.

Table 3 T-Test analysis for gender and proposed variables

	Males		Females			
	M	*SD*	*M*	*SD*	*t(94)*	*p*
GK	4.23	0.96	4.52	0.53	1.03	0.32
GCK	4.21	0.79	4.55	0.52	2.01*	0.04
GPK	4.21	0.68	4.35	0.51	1.93	0.05
GPCK	4.17	0.76	4.50	0.51	1.99*	0.04

Note. *$p < .05$

Table 4 ANOVA analysis for age and proposed variables

	18-19		20-21		22 and above		
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*
GK	4.46	0.59	4.48	0.55	4.52	0.71	0.61
GCK	4.61	0.46	4.45	0.55	4.50	0.70	0.62
GPK	4.55	0.49	4.44	0.54	4.50	0.62	0.40
GPCK	4.53	0.44	4.35	0.54	4.56	0.65	1.42

Table 5 ANOVA analysis for years of playing digital games and proposed variables

	1-5		6-10		11-15		16-20		
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*F*
GK	4.02	0.41	4.66	0.45	4.46	0.71	4.42	0.72	3.62*
GCK	4.14	0.55	4.70	0.43	4.46	0.61	4.36	0.74	3.61*
GPK	4.11	0.45	4.68	0.41	4.45	0.57	4.25	0.74	4.62**
GPCK	4.16	0.58	4.65	0.42	4.39	0.57	4.25	0.74	3.66*

Note. *$p < .05$; **$p < .01$

RQ2: Do pre-service teachers' GK, GCK, GPK, and GPCK differ in terms of their motivation to use digital games for future teaching?

Table 6 shows that the influence of motivation on pre-service teachers' GK (t = 2.34, p < .05), GCK (t = 2.77, p < .01), GPK (t = 3.11, p < .01), and GPCK (t = 2.52, p < .05). Pre-service teacher with high levels of motivation had significantly higher GK, GCK, GPK, and GPCK than those with low levels of motivation. The values of Cohen's d ranged from 0.51 to 0.67, indicating a medium effect.

RQ3: Do pre-service teachers' GK, GCK, GPK, and GPCK differ in terms of their self-efficacy of integrating digital games?

Table 7 shows that the influence of digital game self-efficacy on pre-service teachers' GK (t = 2.60, p < .05), GCK (t = 2.59, p < .05), GPK (t = 3.33, p < .01), and GPCK (t = 2.53, p < .05). Pre-service teacher with high levels of digital game self-efficacy had significantly higher GK, GCK, GPK, and GPCK than those with low levels of digital game self-efficacy. The values of Cohen's d ranged from 0.56 to 0.73, indicating a medium effect.

RQ4: What are the relationships of pre-service teachers' GK, GCK, GPK, and GPCK?

Table 8 shows the correlations among GK, GCK, GPK, and GPCK. All correlations were positive and significant at the p-value of 0.01. GK (r = .71, p < .01), GCK (r = .75, p < .01), and GPK (r = .80, p < .01) were positively related to GPCK. The strongest correlation was found between GPK and GPCK (r = .79, p < .01).

Table 6 T-Test analysis for low and high levels of motivation in GK, GCK, GPK, and GPCK

	Low Motivation		High Motivation				
	M	*SD*	*M*	*SD*	*t(94)*	*p*	*Cohen's d*
GK	4.29	0.67	4.59	0.54	2.34	.021*	0.51
GCK	4.30	0.62	4.63	0.51	2.77	.007**	0.60
GPK	4.26	0.55	4.61	0.50	3.11	.002**	0.67
GPCK	4.27	0.61	4.56	0.49	2.52	.013*	0.54

*Note. *p < .05; **p < .01*

Table 7 T-Test analysis for low and high levels of self-efficacy in GK, GCK, GPK, and GPCK

	Low SE		High SE				
	M	*SD*	*M*	*SD*	*t(94)*	*p*	*Cohen's d*
GK	4.26	0.73	4.62	0.47	2.60	.012*	0.59
GCK	4.31	0.68	4.63	0.45	2.59	.013*	0.56
GPK	4.24	0.62	4.63	0.44	3.33	.002**	0.73
GPCK	4.26	0.65	4.58	0.44	2.53	.015*	0.58

*Note. *p < .05; **p < .01*

Table 8 Correlations among variables

	GK	GCK	GPK	GPCK
GK	—	.75**	.72**	.71**
GCK		—	.74**	.75**
GPK			—	.80**
GPCK				—

Note. **$p < .01$

Table 9 Multiple regression model: GPCK by three predictor variables

Variables	*B*	*SE B*	β	*t*	*p*
GK	.088	.076	.096	1.166	.247
GCK	.234	.086	.241	2.720	.008**
GPK	.632	.083	.621	7.590	.000***

Note. **$p < .01$; ***$p < .001$

RQ5: Do pre-service teachers' GK, GCK, and GPK predict GPCK?

The multiple regression model (see Table 9) was significant, F (3, 92) = 161.26, $p < .001$. The model explained 84% of the variance in GPCK. Among the three independent variables, GCK (t = 2.72, $p < .01$) and GPK (t = 7.59, $p < .001$) significantly predicted GPCK. GK (t = 1.17, $p > .05$) did not significantly predict GPCK. Between the two significant predictors, GPK was the strongest predictor for GPCK.

Discussion

Pre-service teachers' GK, GCK, GPK, and GPCK significantly differ by gender and years of experience of playing digital games

Gender and years of playing digital games had a significant influence on pre-service teachers' TPACK-G. Interestingly, in terms of gender, there seems to be a tendency that females had higher average scores in all four TPACK-G constructs than males. Females had significantly higher GCK and GPCK than males. It implies that compared to male pre-service teachers, female pre-service teachers tended to have higher confidence in using appropriate digital games to deliver targeted subject matter knowledge, along with the capability to adopt proper teaching strategies. This finding contradicts the result of the study conducted by Hsu et al. (2017) where male teachers were found to have higher GK scores than female teachers, but no gender differences in GCK, GPK, and GPCK. The study of Hsu et al. (2017) focused on in-service teachers, but our study on pre-service teachers. Furthermore, most of the TPACK studies appear to show significant differences in favor of male, as the society usually associates males with the use of technology or highly technical tasks (Ergen et al., 2019; Jang & Tsai, 2013; Naaz & Khan, 2018; Yusuf

et al., 2021). In the study of Yusuf et al. (2021), male teachers were found to have significantly higher TK and TCK than female teachers in Nigerian universities. Naaz and Khan (2018) explored pre-service teachers in India, and found that among TPACK constructs, gender difference had a significant impact only on pre-service teachers' TK, with males having higher TK than females. In a meta-analysis study about gender differences conducted by Ergen et al. (2019), significant effect sizes were identified for males in TK, TPK, and TPCK.

Pre-service teachers' experience of playing digital games had a significant influence on their GK, GCK, GPK, and GPCK. Specifically, pre-service teachers who had 6-10 years of experiences with digital games had significantly higher scores in TPACK-G constructs than those with 1-5 years. This finding is resonant with the study of Hsu et al. (2013) in which teachers' experiences with games were found to be influential to their perceptions of TPACK-G.

Levels of motivation and digital game self-efficacy have an impact on pre-service teachers' GK, GCK, GPK, and GPCK

Both motivation and digital game self-efficacy were found to significantly influence GK, GCK, GPK, and GPCK among pre-service teachers. Pre-service teachers with higher levels of motivation to use digital games for future teaching had better GK, GCK, GPK, and GPCK, compared to those with low levels of motivation. Similarly, pre-service teachers who had higher levels of confidence in integrating digital games into teaching, showed higher TPACK-G than their counterparts. These findings provide an evidence to the claim about the impact of motivation and self-efficacy on TPACK, which was rarely examined in prior studies, especially in the contexts of digital games for pre- or in-service teachers (Abbitt, 2011; Dong et al., 2020; Hsu et al., 2017; Keser et al., 2015; Semiz & Ince, 2012; Wang & Zhao, 2021). Wang and Zhao (2021) found pre-service teachers' ICT self-efficacy had a positive influence on their TPACK. Dong et al. (2020) investigated K-12 school teachers' TPACK and found that their computer self-efficacy had a significant effect on TPACK. Our study supports the findings of prior research from Hsu et al. (2017) where both confidence and motivation were found to be positively related to all TPACK-G constructs for in-service teachers. Furthermore, our study confirmed the influences of motivation and self-efficacy for digital game integration on pre-service teachers, which is believed to be the first study of TPACK-G that delineates how motivation and self-efficacy relate to TPACK-G constructs in the context of pre-service teachers.

GCK and GPK significantly predict GPCK

The positive correlations among GK, GCK, GPK, and GPCK found in this study correspond to the finding of previous research (Hsu et al., 2017) in which GCK and GPK

were found to predict GPCK significantly. Within the two significant predictors, GPK was the strongest predictor for GPCK. This finding aligns with the study of Hsu et al. (2017) where GK, GCK and GPK significantly predicted GPCK among in-service teachers. Furthermore, it supports the claim that GPK is the most critical construct for GPCK, in comparison to GK and GCK. This finding suggests that pre-service teachers who possess more GCK and GPK tend to have higher levels of GPCK.

Interestingly, we found that GK did not predict GPCK significantly among pre-service teachers, which is contrary to the study of Hsu et al. (2017) that revealed the significant influence of GK on GPCK for in-service teachers. It may be due to that most of the pre-service teachers in this study were younger generations (about 90% aged between 18-23 years old) who were probably more adept in digital games than in-service teachers who exhibited a large range of skills and experiences with digital games in the study of Hsu et al. (2017).

Conclusion, implications, and limitations

This study has increased our understanding of pre-service teachers' TPACK in digital gaming contexts (TPACK-G), specifically, with the focus on factors such as TPACK-G constructs, motivation, and self-efficacy for digital game integration, as well as their relationships and the influences of personal factors (i.e., age, gender, etc.) on the proposed factors. To our knowledge, this is the first study of TPACK-G for pre-service teachers. The findings of this study not only add to the limited research on TPACK-G in pre-service teacher contexts, but also provide insights into the impact of motivation, self-efficacy, and TPACK-G (i.e., GK, GCK, and GPK) constructs on GPCK. The relation of TPACK-G to motivation and self-efficacy was only investigated in one study that included in-service teachers.

In this study, pre-service teachers' GK, GCK, GPK, and GPCK significantly differed in terms of levels of motivation and self-efficacy. GCK and GPK were found to be significant predictors of GPCK, and GPK was the strongest predictor of GPCK. Additionally, the influences of personal factors on TPACK-G constructs were explored. Gender and prior experiences with digital games were influential to TPACK-G constructs.

In terms of practical implication, this study suggests the importance of offering pre-service teachers opportunities to engage in activities or hands-on projects with the use, design, or development of digital games in teacher education programs. Specifically, activities allowing pre-service teachers to gain their GCK and GPK may significantly help to enhance pre-service teachers' knowledge about the use of digital games in alignment with pedagogical strategies and the subject content, and their willingness, interests, and confidence for adopting or integrating digital games for future teaching. In addition, teacher educators should pay attention to pre-service teachers with low levels of motivation

and self-efficacy in using or integrating digital games for teaching or learning, and provide them with best practices or successful cases about digital game integration in teaching to increase their interests or confidence in using digital games for future teaching. Additional support or resources should be available to pre-service teachers who have less experience with digital games. Hands-on activities that pair pre-service teachers who have less experience with digital games or possess low levels of motivation or self-efficacy in using digital games with those who are more skillful and knowledgeable about digital games may help.

As for research implications, this study adds to the lack of TPACK-G research in the context of pre-service teachers. It also provides evidence to the significant correlations among TPACK-G constructs, and the positive effect of motivation and self-efficacy on TPACK-G. In addition, the significant influence of gender and prior experiences with digital games on TPACK-G was confirmed. Future studies are encouraged to (a) examine TPACK-G in various content areas and among different groups of pre-service teachers from different countries, (b) verify the effect of personal factors, motivation, and self-efficacy on TPCK-G constructs, (c) explore how different design of hands-on activities for digital games may have an impact on pre-service teachers' motivation, self-efficacy, and TPACK-G, and (d) take into account the effect of gender for TPACK-G across different subject areas.

In terms of the limitations of this study, the findings of this study may not be generalized to pre-service teachers from other countries (e.g., Asia, Europe, etc.). The pre-service teachers in this study were from different majors in the College of Education, and we did not take into account the potential impact of content areas on TPACK-G. In addition, there were much more female pre-service teachers than male pre-service teachers in our study because the research participants were all from the College of Education in which it is common to have more female students (i.e., 85% above) than male students. The disproportion of gender distribution may lead to the findings that are more representative of female pre-service teachers than male pre-service teachers.

Abbreviations

CK: Content knowledge; GCK: Game content knowledge; GK: Game knowledge; GPCK: Game pedagogical content knowledge; GPK: Game pedagogical knowledge; ICT: Information and communication technology; IRB: Institutional Review Board; PCK: Pedagogical content knowledge; PK: Pedagogical knowledge; TCK: Technological content knowledge; TK: Technological knowledge; TPACK: Technological pedagogical content knowledge; TPACK-G: Technological pedagogical content knowledge for digital games; TPK: Technological pedagogical knowledge.

Authors' contributions

The authors are responsible for the whole manuscript.

Authors' information

Dr. Yu-Chun Kuo is an Associate Professor of Instructional Technology at Rowan University, United States. Dr. Yu-Tung Kuo is an Assistant Professor at North Carolina Agricultural and Technical State University, United States.

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Author details
[1] Department of Science, Technology, Engineering, Art, and Math Education, Rowan University, United States.
[2] Department of Applied Engineering Technology, North Carolina Agricultural and Technical State University, United States.

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