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BRIDGING TEACHERS' KNOWLEDGE AND ACCEPTANCE: A QUANTITATIVE STUDY ON DIGITAL GAME-BASED LEARNING IN PRIMARY MATHEMATICS

Ngoc Dan Nguyen	Ho Chi Minh City University of Education, Ho Chi Minh City, Vietnam	dannn@hcmue.edu.vn
Vu Thanh Tam Nguyen	University of Social Sciences and Humanities, Vietnam National University Ho Chi Minh City, Ho Chi Minh City, Vietnam	thanhtam@hcmussh.edu.vn
Minh Dung Tang *	Ho Chi Minh City University of Education, Ho Chi Minh City, Vietnam	dungtm@hcmue.edu.vn

* Corresponding author

ABSTRACT

Aim/Purpose	This study examines the relationship between primary school teachers' knowledge and their acceptance of digital game-based learning (DGBL) in mathematics teaching.
Background	The rapid integration of digital technology in education highlights the potential of DGBL in primary mathematics education. Despite its advantages, the acceptance among primary school teachers remains limited, partly due to gaps in specific pedagogical knowledge related to games.
Methodology	Employing Partial Least Squares and Structural Equation Modelling with survey data from 757 primary school teachers, this study tests the hypothesized model based on two theoretical frameworks: the Technological Pedagogical Content Knowledge–Games (TPACK-G) and the Technology Acceptance Model (TAM).
Contribution	This study bridges the TAM framework for digital games and the TPACK-G model, validating the pathways that illustrate their relationship, thus strengthening the connection between these two theoretical perspectives.

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Findings	All the paths within the two theoretical models demonstrate significant relations. In addition, Game Pedagogical Content Knowledge (GPCK) is a critical factor influencing teachers' acceptance, as it significantly impacts their attitudes and behavioral intentions.
Recommendations for Practitioners	This study benefits the future of teacher training and professional development programs aimed at integrating digital games into primary mathematics education. The findings suggest that training should prioritize developing teachers' GPCK and fostering positive attitudes by enhancing perceived usefulness and ease of use.
Recommendations for Researchers	Future researchers could employ qualitative methods, such as in-depth interviews or classroom observations, to enrich insights and validate findings through triangulation.
Impact on Society	Insights into the link between teacher knowledge and acceptance of DGBL can guide the design of training programs for elementary teachers, promoting effective use and improving the quality of mathematics education.
Future Research	Future qualitative research is needed to explore why and how the relations between knowledge and educators' acceptance exist. The present study relied solely on self-reported data from questionnaires, leaving the actual knowledge of teaching mathematics with games and its impact on acceptance unexplored.

Keywords	game-based learning, teachers' adoption, behavioral intention, TPACK-G, TAM

INTRODUCTION

Digital transformation in education has caught up with the pace globally, and digital game-based learning (DGBL) has recently been identified as a significant trend among scholars. Extensive empirical evidence supports DGBL's effectiveness in achieving various educational outcomes. Studies indicate that DGBL can enhance learning effectiveness, student motivation, and engagement in mathematics education by facilitating behavioral changes (Bang et al., 2022; Hussein et al., 2022). Consequently, DGBL holds promise for fostering engaging, participative learning experiences, aligning educational practices with modern standards, and ultimately enhancing student performance. However, one of the weaknesses of educational innovation lies in the slow and hard diffusion of new methods. Despite the growing evidence from research that supports the benefits of DGBL, incorporating this approach into teaching practice remains limited (Denham et al., 2016; Palha & Matić, 2023).

There are multiple reasons why teachers are hesitant to incorporate digital games into their mathematics instruction, such as objective barriers, including a lack of resources and insufficient infrastructure (Dele-Ajayi et al., 2019). Personal factors, including teachers' perceptions, attitudes, beliefs, and knowledge about DGBL, also play a role in this reluctance (Low et al., 2023). It is possible that enhancing teachers' understanding may be more readily influenced than external limitations. Consequently, recent studies have suggested that professional development could effectively increase teachers' acceptance of DGBL (Denham et al., 2016; Villa et al., 2023).

In recent years, considerable research has been done on professional development for teachers to learn to use DGBL in mathematics instruction (Meletiou-Mavrotheris & Prodromou, 2016; Villa et al., 2023). A common feature of these training programs is their focus on helping teachers develop knowledge related to teaching mathematics through digital games. However, while increasing knowledge is beneficial, the relationship between teachers' knowledge and their acceptance of digital games in teaching mathematics still needs to be clarified. Thus, the critical question is whether increasing teachers' TPACK-G leads to a greater acceptance of its use.

The connection between teachers' TPACK and their willingness to adopt technology is not an entirely new concept. However, previous studies have either addressed technology in a general sense (Habibi et al., 2020) or focused on a specific type of technology other than digital games, such as e-schoolbag (Yang et al., 2021) or online professional development (Mailizar et al., 2021). To our knowledge, no specific study has investigated the relationship between primary school teachers' knowledge and acceptance of DGBL in mathematics teaching. This gap indicates a need for further exploration to understand whether enhancing teachers' knowledge in this domain would lead to greater acceptance of digital games in mathematics instruction.

Building on the broader question of whether increasing knowledge about DGBL can help improve the adoption of digital games by primary school teachers in teaching mathematics, this study aims to investigate the following research question: "*What is the relationship between primary school teachers' knowledge of DGBL and their acceptance of its use in mathematics teaching?*"

THEORETICAL FRAMEWORKS

TEACHER'S KNOWLEDGE OF TEACHING MATHEMATICS WITH DIGITAL GAMES

In discussing teachers' knowledge of teaching with technology, one can mention a highly cited model, namely Technological Pedagogical Content Knowledge (TPACK). The TPACK, proposed by Mishra and Koehler (2006), underscores the fundamental belief that teaching with technology is a multi-dimensional task, including several knowledge elements: content, pedagogy, and technology. Each domain presents equal importance for teaching and can crosscut from one another. Intersections between any two of these domains give rise to further knowledge forms: Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), and Technological Content Knowledge (TCK). The merging of the three concepts results in TPCK/TPACK, representing a comprehensive grasp of effectively integrating technology into teaching methods and subject content.

It is important to note that while TPACK addresses technology in a general sense, specific technologies often have unique characteristics that require teachers to possess more advanced knowledge than TPACK offers when teaching with those technologies (Lee & Tsai, 2010). In the case of DGBL, digital games also have distinct features compared to other technologies, primarily stemming from the nature of "games," which typically include elements such as rules, goals, challenges, and quantifiable outcomes (Dickey, 2011; Wouters et al., 2013). Consequently, Hsu et al. (2013) proposed that more than a broad approach to technology might be needed to offer practical guidance for enhancing teacher preparation and professional development in using games for teaching. Therefore, they introduced the Technological Pedagogical Content Knowledge-Game (TPACK-G) framework.

The TPACK-G framework outlines four domains of teacher knowledge, including Game Knowledge (GK), Game Pedagogical Knowledge (GPK), Game Content Knowledge (GCK), and Game Pedagogical Content Knowledge (GPCK) (Hsu et al., 2013). GK refers to understanding general game usage, such as being familiar with gameplay mechanics and having the technical proficiency required to engage with digital games effectively. GPK involves knowledge of how to integrate games with different pedagogical strategies, independent of specific content knowledge – for example, using collaborative features of a game to foster teamwork among learners. GCK pertains to the knowledge of utilizing games to convey or represent content, as the research subjects were preschool teachers, who were considered unlikely to require such knowledge. Finally, GPCK encompasses the ability to apply games in teaching specific content areas, allowing educators to select suitable games that enhance their instructional methods and support student learning outcomes.

Although TPACK-G has only been proposed within the past decade, it has already been utilized in numerous studies for various research purposes. Most prominently, TPACK-G has been employed in research aimed at developing training or professional development solutions for students and teachers to strengthen their capacity to incorporate digital games into teaching (Fu et al., 2022; Pondee et al., 2021; Villa et al., 2023). In addition, other studies have explored the correlation between teachers' TPACK-G and various psychological or cognitive factors, such as beliefs (Hsu et al., 2020) or personal characteristics and intentions (Rüth et al., 2022). In summary, TPACK-G has been validated and applied in recent research and is considered an adequate theoretical framework for describing the knowledge required by teachers to use digital games in their teaching.

Primary School Teachers' Acceptance of Digital Games in Teaching Mathematics

Digital games are considered a technological commodity, so users' acceptance of them is often viewed through the lens of technology acceptance in research. Several models to predict users' acceptance have emerged over the past decades, with one of the most frequently cited being the Technology Acceptance Model (TAM) (Davis et al., 1989). This model predicts and explains technology usage behavior through behavioral intention, attitude, perceived usefulness (PU), and perceived ease of use (PEU) (Davis et al., 1989). Although it has been around for over three decades, the TAM remains one of the most frequently referenced theoretical frameworks for accepting DGBL (Razami & Ibrahim, 2022).

It should be noted that the TAM describes the usage intention and predicts that an individual interacts directly with a given technology. In this case, it means the individuals who play digital games interact directly with them. However, in educational contexts where the teacher employs digital games as an instruction strategy, the teacher is not the direct user of digital games but a facilitator who passes on the games to their students.

For this reason, researchers utilizing the TAM to explain teachers' intentions to use DGBL have made appropriate adjustments. Yeo et al. (2022) recently adapted the TAM model variables and items to fit better using digital games in elementary mathematics instruction. Within the construct of PEU, where teachers are to be questioned regarding the complexity of the digital games system, the authors ask the participants about the complexity of using digital games for students when performing teaching activities. Similarly, PU, representing the system's value to a user in their work, had been modified to represent PU for mathematics learning, focusing on the perception of the teachers in terms of the usefulness of digital games in enhancing mathematical learning among students. Our study considers the adapted model of Yeo et al. (2022), which is extended toward perceived usefulness for mathematics learning (PUML), perceived ease of use (PEU), attitude toward game use (ATT), and behavioral intention to use in math teaching (BIM).

Linking Teachers' Knowledge and Acceptance of DGBL

Previous research has examined TPACK-G and TAM as separate theoretical models, with TPACK-G focusing on teachers' pedagogical knowledge of digital games (Hsu et al., 2013) and TAM emphasizing perceived usefulness and ease of use in technology adoption (Davis et al., 1989). However, studies have rarely explored the intersection of these two models – particularly how teachers' game-based pedagogical content knowledge (GPCK) shapes their perceived ease of use and usefulness, ultimately influencing their attitudes and intentions to integrate digital games into instruction. By integrating TPACK-G within the TAM framework, this study will highlight how teachers' knowledge directly informs their acceptance of DGBL, offering a more comprehensive understanding of the adoption process.

RESEARCH MODEL AND HYPOTHESES

HYPOTHESES ROOTED IN THE TAM

This study is rooted in the TAM, which has been extensively validated and extended in recent studies to explain user behavior towards new technologies. In the original TAM, attitude was a central component posited to influence behavioral intention directly. However, subsequent adaptations of TAM have often excluded attitude, leading to inconsistencies in the model's application across different studies. For instance, some research has demonstrated that attitude plays a critical role in shaping users' intentions and usage behaviors, suggesting that its exclusion could undermine the model's explanatory power (Dwivedi et al., 2017). On the other hand, other studies have found that the model can still be robust without attitude, particularly when focusing on factors like PU and PEU as direct predictors of behavioral intention (Altalhi, 2020). This inconsistency highlights the ongoing debate about the necessity of attitude in TAM. As previously discussed, our study adopts the modified model by Yeo et al. (2022) for primary school teachers teaching mathematics with digital games. In this model, the authors decided to retain the attitude and confirmed its correlations with other variables in the original model by Davis et al. (1989). Based on this, we present the following hypotheses:

H1: PUML positively influences ATT (PUML → ATT).
H2: PEU positively influences ATT (PEU → ATT).
H3: PEU positively influences PUML (PEU → PUML).
H4: ATT positively influences BIM (ATT → BIM).
H5: PUML positively influences BIM (PUML → BIM).

HYPOTHESES ROOTED IN THE TPACK-G

The validated model by Hsu et al. (2013) demonstrated that GK has a significant impact on GPK, and GPK has a significant impact on GPCK for participants who are preservice teachers. Similar results were found in the study by Hsu et al. (2020), where GPK was identified as the crucial factor in developing GPCK for in-service teachers, and GK also had a direct positive impact on GPCK. However, GCK was not found to have an impact on the development of GPCK. Inconsistencies in research related to TPACK are not uncommon; therefore, in this study, we maintain the hypothesis concerning the relationship between GK and GCK, as well as between GCK and GPCK, in the context of primary school teachers in Vietnam teaching mathematics with digital games. Consequently, this study proposes the following hypotheses:

H6: GK positively influences GPK (GK → GPK).
H7: GK positively influences GCK (GK → GCK).
H8: GK positively influences GPK (GK → GCPK).
H9: GPK positively influences GPCK (GPK → GCPK).
H10: GCK positively influences GPCK (GCK → GCPK).

LINKS BETWEEN THE TWO MODELS

As mentioned in the introduction, connecting TPACK and TAM is not entirely new and has been considered in the context of technologies other than digital games. For instance, Yang et al. (2021) studied e-schoolbags and found that TPACK significantly influenced K-12 teachers' PEU and PU. Additionally, Mailizar et al. (2021) research on the acceptance of online professional development courses showed that TPACK affects PEU and PU and influences attitude and behavioral intention. Furthermore, findings from Habibi et al. (2020) involving Indonesian teachers confirmed that teachers' TPACK effectively predicts their integration of information and communication technology into teaching practices, although the effect was small. Drawing on these findings from the literature, we present the following hypotheses for our study:

H11: GCPK positively influences PEU (GPCK → PEU).

H12: GCPK positively influences PUML (GPCK → PUML).
H13: GCPK positively influences ATT (GPCK → ATT).
H14: GCPK positively influences BIM (GPCK → PEU).

Building on the literature review and theoretical framework, we propose our research model, which comprises fourteen hypotheses, presented in Figure 1.

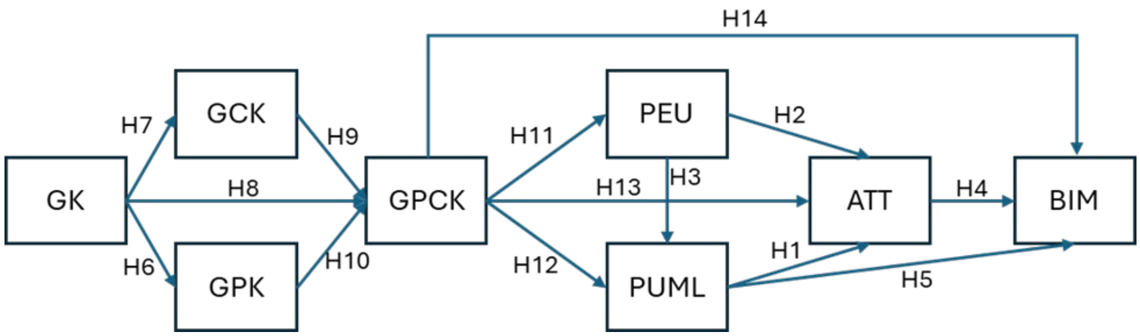

Figure 1. Research hypothesized model

METHODOLOGY

SUBJECTS

This study employed a convenience sampling method, focusing on primary school teachers across several southern provinces in Vietnam. Data collection was conducted through paper-based questionnaires and Google Forms, and the survey period spanned from May to September 2024.

We excluded invalid responses, such as survey responses with missing answers from the final analysis. Additionally, responses that consistently selected the same option across all items, including those with reverse-coded questions, were removed to filter out invalid responses. Following data cleaning procedures, 757 valid responses were obtained for statistical analysis. The profile of those respondents is presented in Table 1.

Table 1. Demographic of respondents

Participant characteristics		Frequency	%
Gender	Male	71	9.4
	Female	686	90.6
Area	City	685	90.5
	Rural area	72	9.5
Teaching experience	1 – 5 years	165	21.8
	6 – 10 years	185	24.8
	Over 10 years	377	49.8

INSTRUMENTS

This study utilized a questionnaire consisting of 27 items to measure factors related to teachers' TPACK-G and acceptance of DGBL. Details of the items are presented in Table 2. The TPACK-G scale utilized in this study was originally adopted by Hsu et al. (2013). However, as the original scale did not include items measuring GCK, additional GCK-related questions were incorporated from Hsu et al. (2020) to ensure comprehensive coverage of the construct. The questionnaire encompasses the following factors: GK with four items, GPK with three items, GCK with four items, and GPCK with three items. The items were translated into Vietnamese and reviewed by two experts: one Vietnamese language specialist with expertise in English linguistics and a Vietnamese researcher who has conducted extensive recent research on technology integration in mathematics education. This language review aimed to ensure that the translated items preserved the original meaning while being comprehensible to Vietnamese respondents.

Table 2. Measurement items description for each construct

Variable	Construct items		Source
PEU	Evaluate the difficulty level of organizing the following math teaching activities with digital games: (1 - Very easy, 4 - Very difficult) (inverse-coded)		Adapted from Yeo et al. (2022)
	PEUML1	Maintain students' focus and active participation during gameplay.	
	PEUML2	Address students' emotions (like frustration) while playing.	
	PEUML3	Handle behavioral challenges, such as students distracting others during gameplay.	
PUML	Evaluate the frequency with which games support students in performing the following tasks: (1 - Never, 5 – Very often)		
	PUML 1	Understanding mathematical concepts.	
	PUML 2	Preparing for advanced mathematics study.	
	PUML 3	Establishing links between related mathematical content.	
ATT	Indicate the level of agreement (1 - Strongly disagree, 5 - Strongly agree)		Adapted from Yeo et al. (2022) and Davis et al. (1989)
	ATT 1	The time and effort invested in using digital math games in the classroom is justified compared to other teaching methods.	
	ATT 2	Digital math games fit my teaching practices.	
	ATT 3	I find teaching mathematics with games enjoyable.	
	ATT 4	I am against the idea of teaching mathematics with games.	
BIM	Indicate the level of agreement (1 - Strongly disagree, 5 - Strongly agree)		Adapted from Yeo et al. (2022)
	BIM 1	I plan to use a game as an introductory example when teaching a new mathematical concept.	
	BIM 2	I intend to mention a game when teaching math content related to the lesson in class.	
	BIM 3	I aim to review and reinforce selected math content based on students' performance in the game.	
GK	Indicate the level of agreement (1 - Strongly disagree, 5 - Strongly agree)		
	GK 1	I can quickly learn how to use digital games.	Adapted from Hsu et al. (2013) and Hsu et al. (2020)
	GK 2	I can easily navigate and adapt to the game interface.	
	GK 3	My technical skills are good enough to play digital games efficiently.	
	GK 4	I can find and download digital games.	
GPK	Indicate the level of agreement (1 - Strongly disagree, 5 - Strongly agree)		
	GPK 1	I know how to use the characteristics of digital games to support teaching.	

Variable	Construct items		Source
	GPK 2	I know the relevant instructional strategies of digital games.	
	GPK 3	I know how to integrate digital games into teaching.	
GCK	Indicate the level of agreement (1 - Strongly disagree, 5 - Strongly agree)		
	GCK 1	I can recognize the subject-related knowledge embedded in digital games.	
	GCK 2	I can determine whether digital games accurately reflect the intended subject matter.	
	GCK 3	I can assess if the core concepts of the subject are effectively represented in digital games.	
	GCK 4	I can evaluate whether the subject matter knowledge is appropriately applied to digital games.	
GPCK	Indicate the level of agreement (1 - Strongly disagree, 5 - Strongly agree)		
	GPCK 1	I can design lessons that effectively integrate math content, digital games, and teaching strategies.	
	GPCK 2	I can create real-world problems based on math concepts and represent them through digital games to engage my students.	
	GPCK 3	I can choose digital games for my classroom that enhance my teaching methods, the math content I teach, and what students learn.	

To measure teachers' acceptance of digital games in teaching mathematics, we adapted the scale from Yeo et al. (2022) with two modifications. First, the Game-Driven Intention to Use a Digital Game factor was excluded since this mainly measured the extent of a teacher's intention to use instructional digital games with a game-focused perspective rather than emphasizing any specific subject area. In contrast, this study explicitly focuses on mathematics education. Second, the attitude factor in Yeo et al. (2022) originally contained only two items: one assessing whether the time and effort spent implementing a digital game in class is valuable compared to other teaching practices, and the other addressing the appropriateness of digital games for classroom instruction. Since attitude is predicted to be a critical factor in our research model, we added two additional items to enhance reliability based on the original TAM (Davis et al., 1989), including "*I enjoy teaching Mathematics with digital games*" and "*I am against teaching Mathematics with digital games*" (inverse-coded). The translation process into Vietnamese followed the same procedure as outlined for the TPACK-G scale, ensuring linguistic accuracy and clarity for Vietnamese participants.

DATA ANALYSIS

Partial Least Squares – Structural Equation Modelling (PLS-SEM) was utilized to analyze the data and examine the proposed hypotheses, given the predictive focus of the research (Hair et al., 2019). Unlike CB-SEM, which requires large samples and assumes data normality, PLS-SEM is more flexible, handling complex models with multiple latent variables, including both reflective and formative constructs. Additionally, PLS-SEM efficiently analyzes moderate sample sizes (757 teachers) while maximizing variance explanation (R^2 values), making it better suited for studies emphasizing prediction rather than pure theory testing. The bootstrapping approach enhances hypothesis testing, ensuring robust path estimations. Alternative methods, such as CB-SEM, were unsuitable due to strict data assumptions, inability to assess complex structural relationships, and limitations in handling latent variables. Besides, the survey was structured by dividing the questionnaire into sections for each construct to reduce CMB at the data collection stage. This segmentation prevented respondents from making direct associations between different variables, minimizing common rater bias and consistency effects.

To evaluate the model using PLS-SEM, both the measurement model, which ensures reliability and validity, and the structural model must be examined. For the reflective constructs within the study's framework, Composite Reliability (CR), rho_A, and Average Variance Extracted (AVE) need to exceed thresholds of 0.7, 0.7, and 0.5, respectively, to confirm the reliability and convergent validity (Ali et al., 2018; Hair et al., 2019).

RESULTS

MEASUREMENT MODEL ASSESSMENT

The measurement model assessment was conducted based on the guidelines Hair et al. (2019) provided regarding each construct's reliability and validity. Table 3 illustrates the factor loadings of each construct, alpha coefficient, CR, and AVE. The Cronbach's alpha values were measured in terms of their reliability analysis, where all constructs had values above the minimum threshold required of 0.70 to ensure internal consistency among their indicators. Additionally, the CR values were greater than the minimum recommended value of 0.70, evidencing the more consistently measured indicators for their intended constructs. The AVE was also used to check for convergent validity, and all constructs had AVE values from 0.50 and above. Hence, the variance that was captured by the constructs was considerable. Among other things, the loadings of each indicator on respective factors were also greater than 0.60, which means that the constructs have excellent convergent validity. Therefore, these findings suggest this model's robustness concerning reliability and validity and can confidently be used for further analysis.

Table 3. Factor loadings, reliability, and convergent validity

	Factor loadings	Cronbach's alpha	Λ	CR	AVE
AT		0.876	0.88	0.915	0.729
AT 1	0.835				
AT 2	0.88				
AT 3	0.89				
AT 4	0.808				
BIM		0.833	0.836	0.9	0.749
BIM 1	0.88				
BIM 2	0.841				
BIM 3	0.876				
GCK		0.922	0.923	0.945	0.811
GCK 1	0.882				
GCK 2	0.924				
GCK 3	0.901				
GCK 4	0.895				
GK		0.874	0.877	0.914	0.727
GK 1	0.853				
GK 2	0.891				
GK 3	0.815				

	Factor loadings	Cronbach's alpha	Λ	CR	AVE
GK 4	0.85				
GPCK		0.91	0.911	0.944	0.848
GPCK 1	0.925				
GPCK 2	0.927				
GPCK 3	0.91				
GPK		0.892	0.894	0.933	0.822
GPK 1	0.896				
GPK 2	0.917				
GPK 3	0.907				
PEU		0.744	0.745	0.854	0.661
PEU 1	0.797				
PEU 2	0.818				
PEU 3	0.824				
PUML		0.76	0.762	0.862	0.675
PUML 1	0.805				
PUML 2	0.808				
PUML 3	0.851				

Discriminant validity was assessed following the Fornell-Larcker criterion (Fornell & Larcker, 1981), which ensures that each construct is separate from others in the model. The square root of the AVE for each construct exceeded the correlations between the constructs, confirming discriminant validity. Specifically, the diagonal values, representing the square root of the AVE for each construct, were consistently greater than the inter-construct correlations, indicating that constructs share more variance with their indicators than with other constructs in the model (see Table 4). This confirms that the constructs in this model exhibit robust discriminant validity, enabling us to test the structural model confidently.

Table 4. Discriminant validity

	ATT	BIM	GCK	GK	GPCK	GPK	PEU	PUML
ATT	0.854							
BI	0.705	0.866						
GCK	0.577	0.561	0.901					
GK	0.562	0.573	0.527	0.852				
GPCK	0.634	0.665	0.723	0.599	0.921			
GPK	0.567	0.56	0.641	0.623	0.696	0.907		
PEU	0.36	0.302	0.349	0.343	0.337	0.306	0.813	
PU	0.522	0.489	0.46	0.434	0.469	0.445	0.304	0.822

Structural Model Assessment

Structural model testing and analysis are conducted following the validation and reliability of the measurement model. In assessing the structural model, the collinearity value (VIF) must be examined to ensure no multicollinearity issues among predictors. As presented in Table 5, all the VIF values are less than 3, which does not show collinearity.

Table 5. VIF value and multicollinearity

Relationship	VIF
ATT → BIM	1.876
GPCK → BIM	1.749
PUML → BIM	1.437
GPCK → ATT	1.353
PEU → ATT	1.164
PUML → ATT	1.322
GPCK → PEU	1.000
GPCK → PUML	1.128
PEU → PUML	1.128
GK → GCK	1.000
GK → GPK	1.000
GK → GPCK	1.711
GCK → GPCK	1.777
GCPK → GPCK	2.094

Table 6 presents the R^2 values, which indicate the proportion of variance in each dependent variable that its predictors can explain. The R^2 value for GPCK is 0.634, indicating that 63.4% of the variance in GPCK is explained by GK, GCK, and GPK. For ATT, 48% of the variance is explained by PEUML, PUML, and GPCK. Similarly, for BIM, R^2= 0.584 indicates that 58.4% of the variance in BIM is explained by ATT, PEU, and PUML. The high R^2 values for GPCK, ATT, and BIM indicate that a substantial proportion of the variance in these constructs is explained by their respective predictors, highlighting the strong predictive power of the model.

Table 6. The value R^2 represents the coefficient of determination

Dependent variables	R^2	Level
ATT	0.480	Moderate
BIM	0.584	High
GCK	0.278	Moderate
GPCK	0.634	High
GPK	0.388	Moderate
PEU	0.113	Low
PUML	0.244	Moderate

Table 7 and Figure 2 present the hypothesis testing results for the proposed research model. The structural model assessment confirmed all the hypothesized relationships. Notably, the path from GPCK to BIM exhibited a significant relationship, with a path coefficient (β) of 0.341 (t=9.680, p=0.000). Similarly, the relationship from GPCK to ATT was also significant and robust, with β=0.469 (t=15.987, p=0.000). Moreover, GPCK showed a strong relationship with both PUML and PEU, with path coefficients of 0.413 (t=11.427, p=0.000) and 0.337 (t= 8.949, p=0.000), respectively.

Table 7. Structural model path coefficient results (direct relationships)

	Path coefficient (β)	Mean	Standard deviation	t-value	p-value	f²
GCK → GPCK	0.431	0.43	0.038	11.359	0.000	0.286
GK → GCK	0.527	0.524	0.034	15.38	0.000	0.385
GK → GPCK	0.18	0.179	0.034	5.381	0.000	0.052
GK → GPK	0.623	0.622	0.026	24.07	0.000	0.633
GPCK → ATT	0.469	0.468	0.029	15.987	0.000	0.312
GPCK → BIM	0.341	0.340	0.035	9.680	0.000	0.160
GPCK → PEU	0.337	0.335	0.038	8.949	0.000	0.128
GPCK → PUML	0.413	0.412	0.036	11.427	0.000	0.200
GPK → GPCK	0.308	0.31	0.036	8.543	0.000	0.124
PEU →ATT	0.121	0.122	0.03	4.073	0.000	0.024
PEU → PUML	0.165	0.163	0.036	4.561	0.000	0.032
PUML → ATT	0.266	0.264	0.031	8.581	0.000	0.103
PUML → BIM	0.101	0.101	0.032	3.214	0.001	0.017

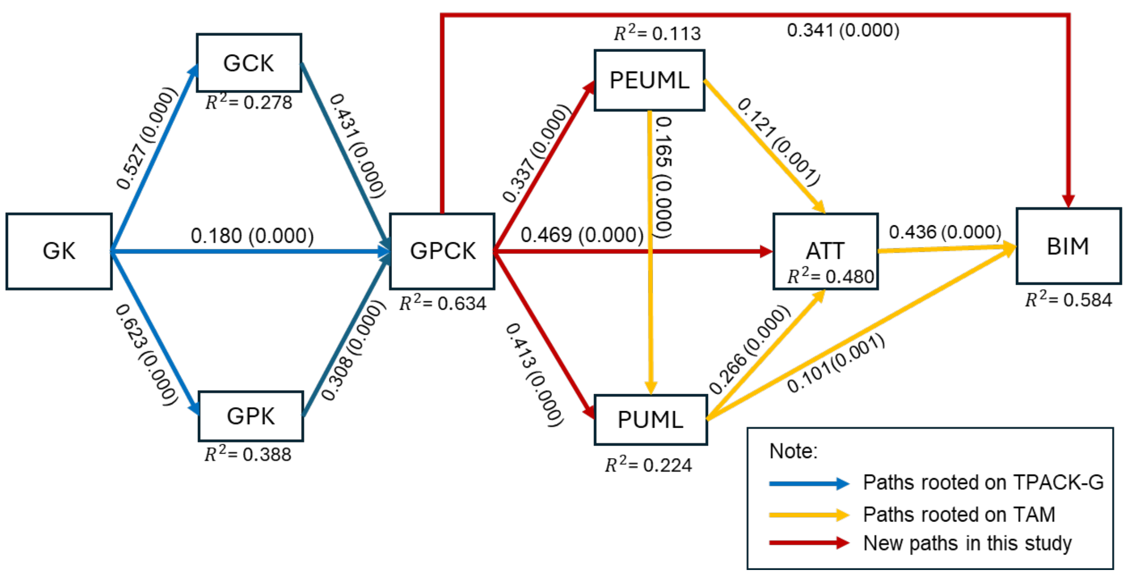

Figure 2. Structural model relationship

Note: The number on the arrow indicates the path coefficient, with the p-value shown in parentheses. The R² value is displayed below the dependent variables.

MEDIATION ANALYSIS

A mediation analysis was performed to assess the indirect effects of the proposed mediators within the model. Table 8 shows that GPCK has a mediating effect on ATT through PUML and PEU. Since GPCK is also directly related to ATT, this is considered partial mediation. Similarly, several other mediation relationships were also identified, including PUML→ATT→BIM, GPCK→PUML→BIM, GK→GCK→GPCK, and GK→GPK→GPCK.

Table 8. Mediation results

	Indirect effect coefficient	Mean	Standard deviation	t-value	p-values
GPCK→PEU→ATT	0.041	0.041	0.011	3.837	0.000
GPCK→PUML→ATT	0.11	0.108	0.014	7.56	0.000
PUML→ATT→BIM	0.116	0.116	0.017	6.861	0.000
GPCK→PUML→BIM	0.042	0.041	0.014	3.082	0.001
GK→GCK→GPCK	0.227	0.227	0.025	9.126	0.000
GK→GPK→GPCK	0.192	0.191	0.023	8.462	0.000

DISCUSSION

Theoretically, the findings from this study, based on a sample of 757 teachers in Vietnam, reaffirm the TAM model adapted for digital games (Yeo et al., 2022) and the TPACK-G model (Hsu et al., 2013), as all the paths in these two models demonstrate significant relations. While previous studies have explored either TAM or TPACK-G separately, this study extends the literature by integrating both frameworks to examine how knowledge influences acceptance. Unlike earlier research that treated pedagogical knowledge and technology acceptance as distinct constructs (Habibi et al., 2020; Mailizar et al., 2021), our findings suggest that GPCK directly influences teachers' perceptions of ease of use and usefulness. This highlights the need for professional development programs that not only enhance pedagogical skills but also address factors influencing teachers' technology acceptance. In the following discussion sections, we focus on those relationships from the perspective of training for primary teachers, specifically exploring which factors can be influenced to enhance their ability and acceptance of using digital games in mathematics teaching.

The results reveal significant relationships between the GPCK and the factors related to teachers' acceptance (PEU, PUML, ATT, and BIM) among primary school teachers. GPCK emerged as a central factor, directly influencing DGBL acceptance through substantial effects on both ATT and BIM. This suggests that teachers with strong GPCK are more likely to perceive DGBL positively and demonstrate a higher intent to integrate it into their teaching practices. Additionally, GPCK impacts PEU and PUML, which act as mediating variables that further enhance teachers' attitudes toward DGBL. These findings highlight the importance of GPCK within the TPACK-G framework as a driver of DGBL acceptance. Thus, it is reasonable that previous studies on primary teacher training in DGBL (Meletiou-Mavrotheris & Prodromou, 2016; Villa et al., 2023) have set the goal of enhancing teachers' GPCK.

The next question arises: What needs to be done to develop GPCK for teachers? This study's results indicate that GPCK relies heavily on a combination of all three knowledge domains: GK, GCK, and GPK. Based on the path coefficient values, it can be observed that GCK and GPK have a more substantial effect in shaping GPCK, with GCK being the stronger of the two. The strong impact of GPK on GPCK has been confirmed in previous studies on TPACK-G; however, the result showing a significant effect of GCK on GPCK contradicts Hsu et al. (2020) or even previous research that focused solely on GK and GPK while developing GPCK, disregarding GCK (Hsu et al., 2015). However, our findings are consistent with those of Koh et al. (2013), who found that TCK (analogous to GCK in this study) had a significant impact on teachers' TPACK, possibly even surpassing the influence of TPK. Therefore, we suggest conducting qualitative research to explain further the role of GCK in forming primary teachers' GPCK, aiming to gain deeper insights into the inconsistencies across these findings.

A common observation between our findings and previous studies is that GK is significantly related to GPCK. Although the path coefficient indicates that GK has a relatively weak direct impact on GPCK, it plays a crucial role in shaping teachers' GCK (β= 0.527, p=0.000) and GPK (β=0.623, p=0.000). Mediation analysis further confirms that GK mainly affects GPCK indirectly through GCK and GPK. Therefore, GK is also an essential factor in developing teachers' GPCK. We observe that recent teacher training programs in DGBL often emphasize GCK, GPK, and GPCK, focusing on activities such as helping teachers evaluate and select appropriate game content, designing game-integrated lesson plans, and practicing teaching with games (Belda-Medina & Calvo-Ferrer, 2022; Meletiou-Mavrotheris & Prodromou, 2016; Villa et al., 2023). On the other hand, GK receives less attention because game-related knowledge (such as understanding game design or the structure of digital games) is often considered outside the primary expertise of an elementary school teacher. However, based on our findings, enhancing GK may positively contribute to developing teachers' GPCK.

Our suggestion is supported by Hsu et al. (2015), who suggest that training teachers' GK enables them to understand and articulate game mechanics, enhancing their capacity to design lessons that effectively integrate games to teach targeted content. These findings suggest that training programs should comprehensively address all TPACK-G knowledge components. A structured approach could begin with familiarizing teachers with digital games (GK), followed by integrating content knowledge and mathematical concepts (GCK) with pedagogical strategies (GPK). Additionally, professional development should incorporate hands-on activities such as designing lessons, testing game-integrated lesson plans, engaging in structured mentoring with experienced educators for feedback, and conducting follow-up sessions to address implementation challenges, ultimately fostering the development of GPCK.

Knowledge is essential, but more is needed for primary teachers to develop an intention to use digital games in mathematics teaching. It should be noted that our results reveal that ATT is the most substantial factor influencing BIM. Furthermore, mediation analysis reveals that ATT serves as an indirect mediator, linking PUML to BIM. Therefore, fostering a positive attitude towards digital games is essential for enhancing DGBL acceptance.

How can primary school teachers develop a more positive ATT? The results of this study align with Yeo et al. (2022) by confirming two hypotheses that PEU and PUML positively impact teachers' ATT. However, our findings add a notable insight: GPCK directly affects ATT, with a path coefficient of 0.463 – stronger than PUML and PEU – and an indirect effect on ATT through PEU and PUML. This suggests that a viable approach to enhancing teachers' ATT may not be to convince them of the games' usefulness and simplicity of use but rather to increase their GPCK. By doing so, teachers can better understand the advantages of using digital games for mathematics learning. To achieve this, teachers could be provided with case studies of successful digital game integration in primary math classrooms to analyze and evaluate. Additionally, enhancing GPCK through teacher training programs can equip teachers with the necessary skills to address common barriers such as technical challenges and classroom management, making them feel that using digital games in teaching Mathematics is not overly complicated.

CONCLUSION

This study highlights the relevance of TAM and TPACK-G in DGBL adoption among primary school teachers in Vietnam. Unlike previous research that examined these frameworks separately, our study is among the first to integrate them, providing a comprehensive perspective on how pedagogical knowledge directly influences technology acceptance. This connection offers a new lens for understanding teachers' adoption of DGBL, with implications beyond Vietnam to other educational contexts where digital game integration is emerging.

Practically, the study benefits the future of teacher training and professional development programs aimed at integrating digital games into primary mathematics education. For educators, our findings emphasize the need for structured training that systematically builds teachers' GPCK, starting from basic game literacy to full pedagogical integration. For policymakers, this study underscores the importance of investing in scalable professional development initiatives and ensuring that school infrastructure supports game-based learning.

A limitation of this study is the reliance on self-reported data, which may lead to some participants providing inaccurate self-assessments. In the Vietnamese context, teachers may worry that their survey responses could impact their professional standing, especially on questions related to TPACK-G that reflect their knowledge and capabilities. Although the researchers assured confidentiality, some teachers may not have expressed their true perspectives. Future research could overcome this limitation by utilizing different data collection methods, such as in-depth interviews or direct observation of teachers using digital games in math instruction. These approaches would provide richer insights and allow for triangulation of findings, thereby enhancing the validity of the conclusions drawn in this study.

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AUTHORS

Ngoc Dan Nguyen serves as a Lecturer in the Department of Primary Education at Ho Chi Minh City University of Education in Vietnam. He earned a master's in mathematics education and is currently a doctoral candidate in the Department of Mathematics and Informatics at Ho Chi Minh City University of Education. His research interests relate to teacher education and technology-enhanced mathematics education, especially digital game-based learning.

Vu Thanh Tam Nguyen is a Lecturer in the Faculty of Education, University of Social Sciences and Humanities, Vietnam National University Ho Chi Minh City. He holds a PhD from the National Taiwan University of Science and Technology. His research interests include the integration of information and communication technology and social-emotional learning within the educational sphere.

Minh Dung Tang earned a PhD in Mathematics-Informatics from Université Grenoble Alpes in France and currently serves as a lecturer at the Department of Mathematics and Informatics at Ho Chi Minh City University of Education in Vietnam. Specializing in teacher education and technology-enhanced mathematics education, he has disseminated research findings through numerous peer-reviewed publications and presentations at both national and international conferences. His work focuses on integrating innovative digital tools into pedagogical practices, thereby advancing mathematics instruction and fostering ongoing professional development among educators.