



Understanding pre-service mathematics teachers' intentions to use GeoGebra: The role of technological pedagogical content knowledge

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Abstract

The research investigated the “Technological Pedagogical Content Knowledge” (TPACK) of pre-service mathematics teachers and its impact on their sustained intention to utilize GeoGebra in teaching mathematics. This study introduced a novel research model by extending the “Unified Theory of Acceptance and Use of Technology” (UTAUT) with TPACK. Through “Structural Equation Modeling” (SEM) applied to data collected from 205 pre-service teachers, the research model was evaluated. The results revealed that factors like effort expectancy, social influence, performance expectancy, and TPACK significantly predicted the continuous use intention of GeoGebra. However, no substantial relationship was found concerning facilitating conditions. The findings have managerial and practical implications for academics, teachers, principals, and decision-makers promoting the use of GeoGebra in educational settings.

Keywords GeoGebra · Mathematics · Education · Preservice teachers · TPACK

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1 Introduction

Rapid changes and remarkable advances in recent technologies over the last two decades have empowered educational institutions to integrate these technologies into their processes. Numerous studies have explored the effectiveness of educational technologies in teaching, and the positive outcomes have propelled the widespread adoption of technology-assisted teaching in educational environments (Yuan et al., 2023a).

In contemporary education, teachers are expected to actively engage students in 21st-century learning experiences and are held accountable for achieving this expectation (Karatas and Arpaci, 2021). Dealing with digital natives, who incorporate technology into every aspect of their lives, demands innovation and fresh ideas to shape and manage classroom environments infused with digital resources (Bueno et al., 2021; Prensky, 2001). In the realm of mathematics, technology enables students to construct geometrical shapes, explore their properties, formulate conjectures, and enhance their mathematical reasoning. Active learning strategies further instill confidence in students' ability to excel in mathematics (Kersaint, 2007). The present elementary mathematics curriculum in Turkiye places a strong emphasis on utilizing technology as a teaching tool. The goal is to offer students opportunities for expressive mathematics learning through the integration of digital resources and platforms (MoNE, 2018).

Pre-service teachers (PSTs) specializing in mathematics must plan, during their training, how they intend to employ specific technologies in their future teaching. Hence, PSTs should receive training on how to leverage the technological opportunities available in education (Yuan et al., 2023b). They should be capable of suggesting appropriate applications from the array of current educational technologies to enhance conceptual understanding of mathematics across diverse contexts. Furthermore, prospective teachers should acquire a solid understanding of fundamental concepts, attitudes, skills, and knowledge essential for effectively implementing technology in educational environments (NETS.T, 2008).

The main concern of this study was understanding teachers' continuous intention to use educational technology in mathematics teaching. Integration of educational technology is significantly influenced by PSTs' perceptions of their readiness to employ it. Effective implementation of educational technology in mathematics requires teachers to internalize the technology. Moreover, the progress and success of technology depend on its practical utilization by the intended users. To better explain, predict, and enhance user engagement, researchers need to comprehend the reasons behind user engagement or their lack of it.

For teachers to effectively use and integrate educational technology into their teaching, they need to cultivate proficiency and understanding of both the educational technology itself and the subject matter. They need to grasp the essence of teaching through the lens of technology (Niess, 2006). Several researchers have delved into the types of technological competencies that a teacher needs to integrate effectively (Graham, 2011; Mouza & Karchmer-Klein, 2013). For instance, Niess et al. (2011) emphasized that PSTs should gain experience in educational technology through the courses they undertake during their undergraduate teacher education

program. Ozgun-Koca et al. (2010) also argue that educational institutions should be responsible for equipping PSTs with adequate skills, knowledge, and encouragement to use educational technology effectively as a tool in their practice. After a solid introduction to various platforms, teachers should have the capability to choose the technology that best aligns with the subject matter content and use it for a specific pedagogical purpose (Harris et al., 2009).

The concept of “Technological Pedagogical Content Knowledge” (TPACK), originally introduced by Koehler and Mishra in 2005, represents the essential knowledge teachers require to effectively integrate educational technology into subject-specific teaching. Mishra and Koehler further refined this framework in subsequent years, offering a comprehensive conceptualization (Mishra & Koehler, 2006, 2008; Niess, 2005). TPACK serves as a guiding theoretical framework for researchers seeking to enhance teachers’ proficiency in utilizing educational technologies in their teaching methodologies (Koehler & Mishra, 2008).

While TPACK has been identified as a significant predictor of technological teaching behavior among mathematics instructors (Anthony et al., 2023; Tang et al., 2023), some studies have shown mixed results, indicating that TPACK might not always significantly influence teachers’ intentions to use technology (Wijaya et al., 2022; Mayer & Girwidz, 2019). There is a noticeable lack of attention given to understanding the intentions of prospective mathematics teachers (PSTs) regarding the integration of educational technology in math classrooms. Considering that the utilization of educational technologies in mathematics education remains below desirable levels, it is imperative to examine the factors affecting teachers’ use of technology, enabling math educators to embrace instructional technologies more effectively (Tang et al., 2023).

Consequently, this study aimed to explore the influencing factors behind pre-service mathematics teachers’ sustained intent to utilize GeoGebra, a dynamic geometry software, drawing from the “Unified Theory of Acceptance and Use of Technology” (UTAUT) and the TPACK framework. The primary objective was to create and evaluate a comprehensive model shedding light on teachers’ continued engagement with GeoGebra, emphasizing its application in dynamic geometry (DGD).

The study serves as a bridge, addressing a critical gap in comprehending the correlation between PSTs’ intent to use GeoGebra, a dynamic mathematics software, and their TPACK. While existing research has examined the factors influencing technology adoption in education and the concept of TPACK in isolation, there is a distinct absence of specific research delving into how TPACK interconnects with the sustained intention to use a specific technology, such as GeoGebra, among PSTs.

By building upon and expanding existing research on technology acceptance, TPACK, and the integration of educational technology, this study seeks to fill this void in understanding PSTs’ inclination to use GeoGebra. The insights gained from this investigation are poised to offer valuable contributions to educational stakeholders and policymakers, facilitating informed decisions and strategies in educational technology integration.

1.1 Dynamic geometry software (DGS)

DGS emerged in the math education literature during the late 1990s as the common term for software specifically developed for geometry education (Lehrer & Chazan, 1998). The three most frequently used DGS tools for supporting research and teaching mathematics are GeoGebra (developed by Hohenwarter in 2006), Geometer's "Sketchpad" (designed by Jackiw in 2001), and "Cabri Geometry" (developed by Laborde & Bellemain in 2005). DGS provides dynamic opportunities for geometry teaching, such as paper folding, visualization with physical manipulators, and activities done with pen and paper (Dogan & Icel, 2011).

The term "dynamic" in DGS signifies that the basic elements constituting geometric shapes can expand and contract together, transforming into one another within the software without distorting the main form (Nurlu Ustun, 2021). Consequently, when students construct geometric concepts with DGS, they can observe the changing and unchanging properties of the concept they have created and examine its relationships with other concepts (Jiang et al., 2015; Nurlu Ustun, 2021).

In particular, the drag-and-drop feature of DGS programs enables students to investigate the relationships between mathematical concepts and observe the outcomes of their operations (Kose et al., 2012). Kose et al. (2012) identified diverse types of dragging available, such as "guided dragging," "bound dragging," "random dragging (wandering dragging)," "dummy locus dragging," "dragging by marking the geometric place (line dragging)," "linked dragging," and "drag testing." For instance, while students explore a mathematical concept through random and purposeful dragging, assuming hidden geometric drags, they can perform a drag test with GeoGebra to investigate the accuracy of the assumption (Kose et al., 2012). With DGS, students can engage in activities like creating moving geometric shapes, verifying measurements numerically, experimenting with different values, manipulating, investigating the relationships within the structure created by dragging, and visualizing how the structure will continue with the assistance of sliders (Arzarello et al., 2002; Balgalmis, 2013; Nurlu Ustun, 2021; Sadan & Uğurel, 2020).

Through DGS activities, students can validate the accuracy of their assumptions about mathematical concepts, derive generalizations, solve problems, and create mathematical models (Marrades & Gutiérrez, 2000; Olsson, 2019; Peressini & Knuth, 2005). DGS represents a vital technological tool; it supports the teaching of mathematics conceptually, enables teachers to instruct and reinforce curriculum-specific topics, and encourages active student participation in the lesson (Tatar et al., 2011).

1.2 GeoGebra

GeoGebra, a DGS, offers innovative opportunities for enhancing mathematics education. The name "GeoGebra" is a fusion of "geometry" and "algebra." Initially conceptualized for Markus Hohenwarter's (2006) thesis project, GeoGebra was developed by a team of software experts (Hohenwarter et al., 2011). Over time, it has been translated into more than seventy languages, making it accessible to students, teachers, and researchers globally. GeoGebra seamlessly integrates algebra, graph-

ing, calculus, geometry, spreadsheets, and statistics into one user-friendly platform (geogebra.org). Its versatility enables its use across all grade levels, from elementary mathematics education to university. Through GeoGebra, users can create interactive teaching tools (Diković, 2009; Paoletti et al., 2017; Richardson, 2009) and develop multiple representations linked to algebraic expressions.

Designed to support students' comprehension of mathematical concepts and their interconnections (Hohenwarter & Jones, 2007), GeoGebra extends beyond being a DGS. It encompasses the capabilities of a computer-based algebra system, a spreadsheet application, augmented reality technology, a Web 2.0 tool, and an automatic theorem prover. Moreover, GeoGebra is compatible with various devices, including tablets, smartphones, laptops, computers, and smart boards (Botana et al., 2015).

2 Theoretical foundation

The theoretical background of the study is rooted in two fundamental approaches to teachers' knowledge: TPACK by Koehler and Mishra (2005) and the UTAUT by Venkatesh et al. (2003). These frameworks are well-established and provide valuable insights into the adoption of technology in educational settings. TPACK underscores the significance of teachers' knowledge and skills in utilizing technology to enrich teaching and learning experiences. The UTAUT model, however, posits that the use of technology is affected by four primary factors: "performance expectancy, effort expectancy, social influence, and facilitating conditions."

2.1 TPACK

A significant body of research underscores the crucial role of teacher knowledge in effective math teaching. The ability to present subject matter in an understandable way for students is foundational for successful teaching (Ball et al., 2008). Various researchers have explored teacher knowledge, resulting in diverse categorizations (Ball, 1990, 2000, 2002; Shulman, 1986). Yet, reaching a consensus on clear-cut components describing teacher knowledge has been challenging, primarily due to the complex and integrated nature of teacher knowledge. As aptly put by Fennema and Franke (1992), "It is a large, integrated, and functioning system whose components are difficult to isolate" (p. 148). Consequently, researchers often resort to Shulman's (1986) broad categorization, which identifies three aspects of teachers' knowledge: "subject matter knowledge, pedagogical content knowledge, and curricular knowledge."

"Subject matter knowledge" pertains to the understanding of concepts, facts, and truths within a particular domain (Shulman, 1986). It encompasses not only the grasp of essential facts and concepts but also the ability to explain their significance and interrelationships with other concepts (Shulman, 1986). The second aspect, "pedagogical content knowledge," focuses on subject matter knowledge specifically tailored for teaching. It encompasses various facets of teaching knowledge, such as appropriate representations, powerful analogies, effective examples, and explanations required to convey ideas (Shulman, 1986). Additionally, it involves recognizing

the challenging and straightforward aspects of specific topics and gauging students' comprehension levels (Shulman, 1986). The third aspect, curricular knowledge, involves understanding the prescribed programs for teaching specific subjects and topics at various levels, familiarity with available instructional materials related to these programs, and discerning the appropriateness of programs or curriculum materials for specific contexts (Shulman, 1986).

Building on these studies, Hill and Ball (2004) further delineated the specific types of knowledge essential for mathematics teachers. They extended Shulman's classifications of teacher knowledge to encompass "specialized content knowledge," "general content knowledge," "knowledge linking content and students," "knowledge bridging content and teaching," and "knowledge concerning the curriculum." "Common knowledge of content" refers to a solid foundation in general mathematics, vital for solving mathematical problems. In contrast, specialized "knowledge of content" entails knowledge of how to teach mathematics for comprehension. To effectively connect students with content, Ball and Cohen (1999) emphasize the necessity of pedagogical knowledge: "To connect students with content in effective ways, teachers need a repertoire of ways to engage learners effectively and the capacity to adapt and shift modes in response to students" (Ball & Cohen, 1999, p. 9). Ball et al. (2008) adopt a model to delineate domains of mathematical knowledge for teaching.

However, these theories discussed teacher knowledge without a specific technological component. In the early 21st century, technology, which was not specific to teaching, has become an integral part of education. Therefore, teacher education programs should incorporate specific technologies relevant to their subject area in their curriculum to teach prospective teachers how to effectively use educational technology in their teaching activities. Besides "pedagogical content knowledge," skills, and "subject matter knowledge" to apply the curriculum based on this knowledge, teachers also require techno-pedagogical content knowledge (Pierson, 2001).

Integrating technology into math education represents a critical aspect of mathematics teachers' TPACK. This involves understanding which problems are effective for conceptual understanding, how to sequence problems, and which representations and technologies best support learning specific concepts. Evaluations of large-scale computer distribution programs in schools suggest that teachers' professional development is crucial for successful technology integration in classroom practices (Hoyles & Langrange, 2010; Clark-Wilson et al., 2014). When teachers are proficient in using technology, students can realize their full potential as a powerful educational tool (Drijvers et al., 2010).

The TPACK framework comprises three fundamental knowledge constructs that teachers possess and develop: "Content knowledge" (CK) or subject matter knowledge, "pedagogical knowledge" (PK) or teaching and learning methods, and "technological knowledge" (TK) or "knowledge of technology" and technological tools. The linkages between TK, CK, and PK also lead to the development of three additional characteristics of technology integration knowledge. These aspects are "technological content knowledge" (TCK) or knowledge of using technology to explain subject matter, "technological pedagogical knowledge" (TPK), or "knowledge of using technology" to apply various teaching methods, and "pedagogical content knowledge" (PCK)—knowledge of different teaching methods specific to subject matter content

(Koehler & Mishra, 2009; Koh & Divaharan, 2011). Originally, TPACK was written as TPCK, but it was later changed to TPACK for easier pronunciation. Moreover, Jaipal and Figg (2010) expanded TPACK as the “Total PACKage,” referring to the comprehensive knowledge required by teachers to effectively integrate the necessary technology into their teaching. According to its creators, TPACK encompasses an understanding of “how technology can help address some of the problems that students face...and knowledge of how technologies can be used to build on existing knowledge to develop new epistemologies or strengthen old ones” (Koehler & Mishra, 2009, p. 66).

It is necessary to turn teacher knowledge into techno-pedagogical forms to successfully integrate educational technology into the classroom. To increase student comprehension, teachers must identify the most effective ways to represent the subject, the most persuasive analogies, examples, illustrations, and demonstrations, as well as how to represent and express the subject. This transformation of knowledge into technology-based activities, employing the most suitable instructional strategies for the subject matter topic, embodies Shulman’s (1986) concept of PCK.

The elucidation of this model implies that TPACK is different from knowing the three ideas separately. The present strategy views TPACK as a fresh and combined form of information that is superior to the sum of its parts. The term “technological, content, and pedagogical knowledge” (TPACK) denotes a modified understanding of the concepts, creating a distinctive body of knowledge (Angeli & Valanides, 2009).

2.2 UTAUT

Over the past three decades, a plethora of models and theories have been proposed to guide the integration of educational technology. These theories and models aim to explain and facilitate the acceptance and effective use of technology in educational settings. One of the most prevalent and widely utilized models is the “Technology Acceptance Model” (TAM), first proposed by (Davis, 1989). TAM has been employed to interpret user behavior in various contexts (Wu et al., 2008). Within this model, “user acceptance” is a pivotal factor to be considered by researchers (Davis, 1989). Particularly in educational contexts, students’ intentions to use educational technology serve as strong indicators of their success (Liaw et al., 2007; Venkatesh & Davis, 2000).

Building on the foundation of TAM and other technology acceptance frameworks, the “Unified Theory of Acceptance and Use of Technology” (UTAUT) was proposed by (Venkatesh et al., 2003). UTAUT is a comprehensive theoretical framework designed to elucidate how individuals perceive and adopt technology across various domains. It has become a prominent tool for analyzing user acceptance of different technologies (Afacan Adanir & Cinar, 2021). UTAUT identifies four constructs: “Performance expectancy, effort expectancy, social influence, and facilitating conditions,” each of which significantly influences an individual’s intentions to use technology.

“Performance expectancy” reflects an “individual’s belief in the extent to which using a particular technology will enhance their job or task performance.” “Effort expectancy” pertains to the perception of ease and minimal effort associated with using the technol-

ogy. “Social influence” gauges the influence of important individuals or groups in an individual’s life, shaping their perception that they should use the technology. Lastly, the “facilitating conditions” factor encompasses individuals’ belief in the availability of sufficient support in terms of technical infrastructure, resources, and training necessary to effectively use the technology (Venkatesh et al., 2003).

In the present study, continuous intention to use GeoGebra, a dynamic mathematics software, will be predicted based on the factors outlined in the UTAUT model. The hypothesis suggests that continuous intention will be stronger when pre-service teachers (PSTs) perceive GeoGebra as useful and easy to use, and when they receive support and encouragement from their peers and instructors. Additionally, PSTs’ level of TPACK is expected to positively influence their continuous intention to use GeoGebra, as a solid TPACK equips them to seamlessly integrate the software into their teaching practices.

The UTAUT serves as a valuable tool in the design and implementation of innovative technologies, offering insights into the factors that impact user acceptance and suggesting ways to enhance adoption rates. Moreover, the UTAUT considers individual characteristics such as gender, age, experience, and willingness as additional factors that may impact technology adoption in educational settings. Understanding and leveraging these determinants are fundamental for successful technology integration, enhancing the educational experience and outcomes for both teachers and students.

3 Research model and hypotheses

3.1 Research model

The proposed research model posits that the adoption of GeoGebra, a dynamic mathematics software, by pre-service teachers (PSTs), is influenced by factors associated with both the UTAUT and “Technological Pedagogical Content Knowledge” (TPACK). The study examined the structural model shown in Fig. 1 to understand the factors predicting the continuous intention to use GeoGebra among pre-service mathematics teachers. The research hypothesis posited that the continuous intention to use GeoGebra by pre-service teachers is influenced by factors encompassing both the UTAUT model and TPACK.

3.2 Research hypotheses

3.2.1 Performance expectancy (PE)

Venkatesh et al. (2003) defined PE as “individuals’ beliefs that using a new technology will enhance their job performance.” Previous studies have consistently indicated that performance expectancy positively affects behavioral intention (Arpaci et al., 2022; Chang et al., 2012; Wang & Shih, 2009). In the study, PE is framed as the degree to which a pre-service teacher believes that using technology like GeoGebra will improve their teaching performance in mathematics. Formally, the first hypothesis is outlined as follows:

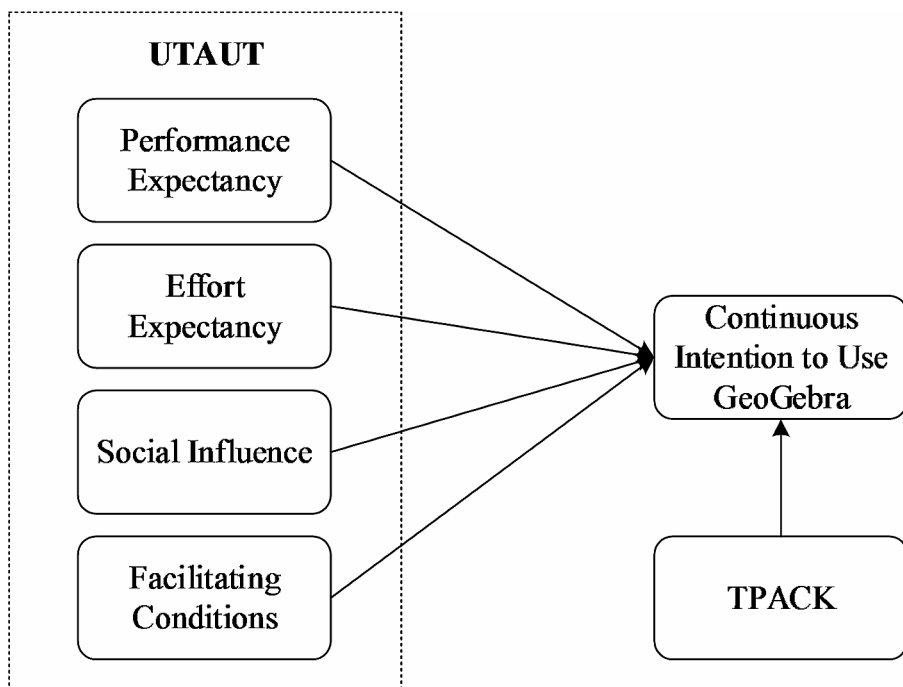


Fig. 1 Research model

H1 Pre-service mathematics teachers' performance expectancy of GeoGebra will positively influence their continuous intention to use GeoGebra.

3.2.2 Effort expectancy (EE)

EE, a key construct in technology acceptance, has been consistently demonstrated to significantly impact technology acceptance in various research studies (Arpaci, 2015, 2016; Kim & Lee, 2020). Effort expectancy is primarily associated with the perception that a technology tool can be easily utilized in the classroom environment. GeoGebra simplifies complex mathematical concepts. In the study, the assumption is that if teachers using GeoGebra perceive it to be easy to use, they will exhibit more positive and accepting behavior toward the program. This hypothesis is founded on the notion that technology that is user-friendly and intuitive enhances user acceptance. The ease of use of GeoGebra is anticipated to influence users' willingness to adopt it and determine the extent to which they utilize it to enhance their learning outcomes. Thus, the following hypothesis will be evaluated:

H2 Pre-service mathematics teachers' effort expectancy of GeoGebra will positively influence their continuous intention to use GeoGebra.

3.2.3 Social influence (SI)

SI refers to pre-service teachers' perception that people who hold significance to them believe they should take a specific action—specifically, using GeoGebra in mathematics (Venkatesh et al., 2003). Prior findings consistently demonstrated that SI has a positive impact on behavioral intentions (Alshurideh et al., 2023; Al-Emran et al., 2020; Park et al., 2007; Gupta et al., 2008; Pai & Tu, 2011). Social influence holds the potential to positively impact PSTs' continuous intention to use technology. Therefore, the following hypothesis is proposed:

H3 Social influence from peers and instructors will positively influence pre-service mathematics teachers' continuous intention to use GeoGebra.

3.2.4 Facilitating conditions (FC)

FC, encompassing the availability of resources that can encourage the usage of technology, emerges as a critical factor influencing the continuous intention of “pre-service teachers” (PSTs) to use educational technologies like GeoGebra. PSTs' willingness to integrate GeoGebra into their learning and teaching practices is significantly shaped by their perceptions of the accessibility to technical assistance and the overall compatibility of the tool with their teaching context (Al-Sharafi et al., 2023). This compatibility is gauged by the degree to which the necessary infrastructure is available to support its use (Venkatesh et al., 2003). As a dependent variable, continuous intention encapsulates PSTs' intentions to continue using the educational technology in question. Based on this rationale, the following hypothesis is proposed:

H4 Facilitating conditions will exert a positive impact on pre-service mathematics teachers' continuous intention to use GeoGebra.

3.2.5 TPACK

In the existing literature, limited research has delved into investigating the role of “Technological Pedagogical Content Knowledge” (TPACK) in the technology adoption process (Mohammad-Salehi et al., 2021). Recent studies, however, have shed light on the positive and direct influence of TPACK on both “perceived usefulness” and “perceived ease of use” (Mei et al., 2018; Joo et al., 2018; Prasojo et al., 2020). TPACK embodies the interconnections across various domains of knowledge and delineates critical aspects of the knowledge base that a teacher needs to effectively integrate educational technology into their teaching practice. Given these insights, the current study aims to investigate the relationship between TPACK and the continuous intention to use GeoGebra. Based on the present research context, the following hypothesis is proposed:

H5 Pre-service mathematics teachers' TPACK will exert a positive impact on their continuous intention to use GeoGebra.

4 Method

4.1 Sample and procedure

The study involved 205 pre-service teachers (PSTs) with an average age of 22.87 years $\pm$ 5.68 (ranging from 18 to 47). In total, 22.4% of the participants were male (46 males and 159 females). Among the participants, 85.9% were prospective primary school mathematics teachers, and the remaining 14.1% were prospective mathematics teachers at the high school level. The study employed purposive sampling to achieve its objectives, and participants were required to utilize a mathematics application. Additionally, 99% of the participants reported using at least one of the following mathematics applications: GeoGebra, Cabri, Desmos, Symbolab, Mathway, Wolfram, and Wordwall. Only 1% of the participants mentioned a preference for Excel over these applications.

4.2 Instruments

The online survey comprised three categories: demographics, 17 five-point Likert items (refer to Appendix A for the scale items) assessing the UTAUT constructs, and five items evaluating “Technological Pedagogical Content Knowledge” (TPACK), which refers to “teachers’ understanding of how various technologies can be effectively utilized in teaching, recognizing that technology can alter teaching methodologies” (Schmidt et al., 2009, p. 134). The items assessing TPACK were adapted from the scale proposed by (Schmidt et al., 2009) and translated into Turkish by (Ozturk & Horzum, 2011). In the original and adapted studies, Cronbach’s alpha estimate for the TPACK was reported as 0.86 and 0.89, respectively.

Three items measured “Performance Expectancy” (PE), four items measured “Effort Expectancy” (EE), three items measured “Social Influence” (SI), four items measured “Facilitating Conditions” (FC), and three items measured “Continuous Intention to Use” were adapted from (Venkatesh et al., 2016). The internal consistency coefficients for these constructs were reported to be 0.75 or greater, indicating high reliability for all subscales.

5 Results

5.1 Data analysis

“Bartlett’s test for sphericity” (χ^2 (DF=253)=2842.898, $p < .001$) and the “Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy” (0.892) confirmed the factorability of the data. Communalities, ranging between 0.489 and 0.665, exceeded the

threshold of 0.30 (Child, 2006). Factor loadings, ranging between 0.519 and 0.871, surpassed the threshold value of 0.40 (Hair et al., 2019). The Cronbach's alpha for the total scale was calculated as 0.919, indicating high internal consistency. Additionally, skewness ($SE=0.170$) and kurtosis ($SE=0.338$) measures fell within the range of -3 to +3, suggesting that the data exhibit a normal distribution (Hair et al., 2019). Normal test results and descriptive statistics are shown in Table 1.

5.2 Convergent and discriminant validity

As recommended by Fornell and Larcker (1981), tests for discriminant and convergent validity were conducted by calculating the “average variance extracted” (AVE) and “composite reliability” (CR) values. The results indicated that CR values exceeded the threshold of 0.70. Furthermore, “Cronbach's alpha” (CA) coefficients for the factors ranged between 0.77 and 0.89, indicating strong internal reliability of the subscales. AVE values were also higher than the threshold of 0.50 (Fornell & Larcker, 1981), providing robust evidence for convergent validity. As depicted in Table 2, “discriminant validity” was confirmed, as “the square root of the AVE” values shown in the diagonal (in bold) exceeded the correlations between the respective construct and the other constructs included in the proposed model. Moreover, the findings revealed positive correlations between TPACK and UTAUT constructs.

Table 1 Descriptive statistics and normality

Items	Range	Min	Max	Mean	SD	Communalities	Load	Skewness	Kurtosis
PE1	3	2	5	4.25	0.799	0.572	0.728	-0.770	-0.164
PE2	4	1	5	4.25	0.811	0.543	0.702	-0.819	0.220
PE3	3	2	5	4.51	0.676	0.580	0.744	-1.150	0.467
EE1	4	1	5	3.78	0.954	0.553	0.711	-0.323	-0.531
EE2	4	1	5	3.98	0.936	0.586	0.647	-0.530	-0.512
EE3	4	1	5	3.72	0.969	0.615	0.647	-0.319	-0.434
EE4	4	1	5	3.62	1.015	0.555	0.667	-0.202	-0.707
SI1	4	1	5	3.91	1.105	0.618	0.821	-0.805	-0.201
SI2	4	1	5	3.72	1.186	0.602	0.809	-0.638	-0.503
SI3	4	1	5	4.00	1.041	0.642	0.871	-0.965	0.417
FC1	4	1	5	4.14	1.031	0.610	0.696	-1.046	0.233
FC2	4	1	5	3.68	0.982	0.665	0.766	-0.319	-0.620
FC3	3	2	5	4.18	0.829	0.528	0.611	-0.557	-0.765
FC4	4	1	5	4.18	0.976	0.502	0.519	-1.328	1.534
CIU1	4	1	5	3.88	1.010	0.624	0.598	-0.676	-0.228
CIU2	4	1	5	2.88	1.142	0.625	0.849	0.242	-0.571
CIU3	4	1	5	3.18	1.035	0.589	0.825	0.141	-0.703
TPACK1	3	2	5	4.02	0.804	0.615	0.832	-0.435	-0.398
TPACK2	3	2	5	4.15	0.749	0.554	0.793	-0.467	-0.422
TPACK3	4	1	5	3.87	1.002	0.593	0.718	-0.718	0.115
TPACK4	3	2	5	3.92	0.884	0.516	0.812	-0.352	-0.718
TPACK5	4	1	5	3.93	0.834	0.523	0.755	-0.527	0.089

Table 2 Convergent and discriminant validity

Construct	CR	AVE	CA	FC	CIU	PE	EE	SI	TPACK
FC	0.794	0.564	0.771	0.751					
CIU	0.843	0.642	0.823	0.470	0.801				
PE	0.788	0.554	0.784	0.546	0.563	0.744			
EE	0.896	0.684	0.894	0.750	0.545	0.664	0.827		
SI	0.894	0.738	0.891	0.338	0.465	0.550	0.276	0.859	
TPACK	0.854	0.541	0.882	0.634	0.508	0.443	0.514	0.275	0.735

Square roots of AVE values shown in bold on diagonals

5.3 Model fit measures

“Confirmatory Factor Analysis” (CFA) was performed using SPSS AMOS to validate both the structural and measurement models. The structural model incorporates hypothesized connections among latent variables and links between these latent variables and observable variables whose values are present in the dataset. The results revealed that the structural model exhibited an adequate fit to the data: [$\chi^2/DF=2.065$, $\chi^2=363.513$, $DF=176$, $GFI=0.859$, $AGFI=0.815$, $CFI=0.923$, $TLI=0.909$, $IFI=0.924$, $SRMR=0.1709$, $RMSEA=0.072$, $LO90=0.062$, $HI90=0.083$]. Furthermore, Table 3 displays the model fit measures for the measurement model, signifying that the model fit is deemed acceptable.

5.4 Hypothesis testing results

The study utilized a “Structural Equation Modeling” (SEM) approach to assess the study hypotheses. The findings presented in Table 4 indicated that UTAUT factors of

Table 3 Model Fit Measures

Measure	Estimate	Threshold	Interpretation
CMIN	328.563	--	--
DF	192	--	--
CMIN/DF	1.711	Between 1 and 3	Excellent
CFI	0.946	>0.95	Acceptable
SRMR	0.059	<0.08	Excellent
RMSEA	0.059	<0.06	Excellent
PClose	0.086	>0.05	Excellent

Table 4 Hypothesis testing results

	Path	Estimate	Std. Est.	S.E.	C.R.	P
H1	PE→CIU	0.195	0.179	0.083	2.334	0.02*
H2	EE→CIU	0.286	0.347	0.063	4.564	***
H3	SI→CIU	0.233	0.305	0.058	4.046	***
H4	FC→CIU	−0.054	−0.059	0.067	−0.804	0.421
H5	TPACK→CIU	0.382	0.307	0.099	3.874	***

* $p<.05$, *** $p<.001$

“Performance Expectancy” (PE), “Effort Expectancy” (EE), and “Social Influence” (SI) had a positively significant impact on the continuous intention to use (CIU) of GeoGebra ($\beta=0.179, p=.02$; $\beta=0.347, p<.001$; $\beta=0.305, p<.001$), confirming H1, H2, and H3. The findings further supported H5, with TPACK demonstrating a positive relationship with CIU ($\beta=0.307, p<.001$). However, the findings did not support H4, as the link between “Facilitating Conditions” (FC) and CIU was not significant ($p=.421$). In total, these factors explain 40% of the variance in CIU ($e=0.31$).

6 Discussion

This study aimed to predict the constructs underlying Pre-Service Teachers’ (PSTs) intentions to use GeoGebra. Outcomes were measured in terms of five factors: “Performance expectancy, effort expectancy, social influence, facilitating conditions, and TPACK.” According to the developed model (based on UTAUT and TPACK), four factors— “performance expectancy, effort expectancy, social influence, and TPACK”—are significantly correlated with the continuous intention to use GeoGebra, while no significant relation is reported regarding “facilitating conditions.”

Based on the findings of the structural model, “performance expectancy” has a positive impact on PSTs’ continuous intention to use GeoGebra. The continuous intention to use GeoGebra is crucial for PSTs’ effective integration of educational technology into their learning and teaching practice. That is, PSTs who perceive GeoGebra as useful in enhancing their learning and teaching of mathematics are more likely to use it in their future classes. Based on the current study, participants believed in general that the use of GeoGebra was necessary for their professional development, that it supports their teaching of mathematics, and that it increases their productivity. The teacher candidates find GeoGebra useful for teaching, and they are planning to choose to use GeoGebra in their professional lives. This finding shows that “performance expectancy” significantly impacts continuous intention to use GeoGebra. This result is consistent with much previous research (Taamneh et al., 2022; Teo et al., 2019; Venkatesh et al., 2003). However, there are also studies claiming that performance expectancy has no significant effect on behavioral intention (Yuan et al., 2023a).

Another direct determinant of PST’s continuous intention to use GeoGebra was “effort expectancy.” This aligns with many previous studies claiming that PSTs’ perception of “effort expectancy” plays a pivotal role in shaping their intention to incorporate technology into their learning and teaching (Teo et al., 2019; Yuan et al., 2023a). PSTs who perceive GeoGebra as easy to use are more likely to use it. According to the results of this study, teacher candidates with technical knowledge of GeoGebra stated that using GeoGebra is easy and that they intend to continue using GeoGebra professionally shortly. The findings of the structural model were that “effort expectancy” has a positively significant effect on PSTs’ continuous intention to use GeoGebra. When PSTs perceive GeoGebra as user-friendly, intuitive, and not demanding excessive time or energy investment, their intentions to use it become more pronounced.

Experiences with the software during training or coursework can enhance PSTs' confidence in the ability to effectively implement GeoGebra in their future classrooms. Addressing any barriers to use and providing comprehensive training that highlights the features and benefits of GeoGebra can mitigate concerns related to effort expectancy. By fostering a sense of competence and reducing perceived complexity, educational institutions can encourage PSTs to embrace GeoGebra as a valuable tool for enriching mathematics education, bolstering their intention to integrate it into their teaching repertoire. This finding conflicts with some other recent studies that have claimed there is no significant effect of "effort expectancy" on behavioral intention (Taamneh et al., 2022).

According to the structural model of the present study, "social influence" is also an indicator of PSTs' continuous intention to use GeoGebra. "Social influence" is related to the people around prospective teachers. PSTs felt that people who directly affect their behavior (e.g., instructors, peers, and family members) expect them to use GeoGebra professionally. In this case, "social influence" is positively associated with prospective teachers' continuous intention to use GeoGebra, which aligns with the research hypothesis and findings from prior studies (Venkatesh et al., 2003, 2016; Teo et al., 2019; Yuan et al., 2023a).

"Social influence" plays a critical role in shaping the intentions of PSTs to embrace and utilize educational technologies like GeoGebra. As future educators, PSTs are inherently influenced by the perceptions, recommendations, and experiences of their peers, mentors, and instructors. Positive interactions and discussions among peers about the benefits of GeoGebra can create a supportive environment that encourages its adoption. Additionally, guidance and endorsements from experienced educators who have successfully integrated GeoGebra into their teaching practices can serve as powerful motivators. Observing these role models effectively using GeoGebra to enhance their mathematics instruction can alleviate doubts and uncertainties among PSTs, increasing their confidence and intention to integrate this technology into their future classrooms and lessons. By fostering a culture of collaboration, sharing best practices, and highlighting successful case studies, educational institutions can harness the strength of social influence to inspire PSTs to embrace GeoGebra as a tool for enriching mathematics education. However, other studies have argued that there is no effect of social influence on behavioral intention (Taamneh et al., 2022).

The final aspect of UTAUT addressed within this study was "facilitating conditions." Surprisingly, the results show that there is no direct effect on PSTs' continuous intention to use GeoGebra. As stated previously, facilitating conditions are "the degree to which an individual believes the necessary infrastructure exists to support the use of new technology" (Venkatesh et al., 2003). Based on the study findings, it is evident that PSTs anticipate a lack of essential resources or knowledge to effectively utilize GeoGebra in their future classrooms. Additionally, they express concern about encountering challenges related to GeoGebra usage within a school setting, often lacking access to expert assistance to address such issues. Moreover, they hold the perception that seeking help from others during difficulties with GeoGebra may not be a viable option. In contrast, several prior studies (Mohammad-Salehi et al., 2021; Taamneh et al., 2022; Venkatesh et al., 2003; Yuan et al., 2023a) found that "facilitating conditions" are a significant factor influencing teachers' usage behavior with

technology. To encourage PSTs to have more confidence in their support systems, it is important to note that classrooms have access to the necessary technology to use GeoGebra—for example, access to a computer or a tablet with the internet. PSTs should also receive adequate training and support to effectively use GeoGebra in their teaching. This can include attending workshops, webinars, or online courses. When these facilitating conditions are favorable, PSTs are more likely to develop positive attitudes toward GeoGebra and exhibit higher levels of intention to incorporate it into their future classrooms.

The last indicator of PSTs' continuous intention to use GeoGebra was their TPACK level. That model emphasizes the interplay between three aspects of knowledge: "technology, pedagogy, and content knowledge." The TPACK model emphasizes that successful integration of educational technology into teaching necessitates teachers possess a profound comprehension of the content they are teaching, effective pedagogical strategies, and a clear understanding of how technology can enhance lessons on the specific subject matter being taught. According to the current study's findings, TPACK as a type of teachers' knowledge is a significant determinant of PSTs' continuous intention to use GeoGebra.

7 Conclusion

7.1 Managerial and practical implications

The findings of the current study have highlighted crucial implications for educators, teacher trainers, and researchers involved in the use of GeoGebra and DGS in educational contexts. The effective integration of educational technology in math education necessitates teachers' internalization of the educational technology. Therefore, teacher candidates should carefully select technologies that align with their teaching approaches and enhance their students' learning experiences. Prospective teachers should strive to gain practical experience in adapting the use of GeoGebra to various teaching activities. According to the results, the success of technology in the classroom heavily relies on its actual utilization. As per the "Technological Pedagogical Content Knowledge" (TPACK) model, "Pre-Service Teachers" (PSTs) with higher levels of TPACK are more likely to effectively integrate GeoGebra into their learning and teaching practices.

The findings indicated that the UTAUT model aptly explains the process PSTs undergo when adopting and using GeoGebra. It is imperative to urgently integrate educational technologies into teacher education programs to foster the development of TPACK in PSTs. Furthermore, exposure to effective training and support systems capable of addressing technical challenges can significantly enhance PSTs' confidence and proficiency in using DGS, boosting their motivation to adopt GeoGebra as an integral part of their teaching toolkit.

This study contributes to the current body of knowledge by formulating a novel model and offering new perspectives beneficial to school principals and governmental entities concerning the factors that facilitate the acceptance of dynamic geometry software (i.e., GeoGebra). To improve teachers' utilization of dynamic math software,

the government needs to dedicate ample resources to ensure schools are equipped with adequate software and hardware. Correspondingly, schools should provide fitting curriculum resources concerning dynamic math software, and teachers should actively engage in acquiring proficiency in effectively employing this technology within their classrooms. With the acknowledgment by educational institutions and teacher education programs regarding the crucial role of offering substantial support and training in integrating educational software such as GeoGebra, PSTs are better prepared to utilize the advantages of these technological tools. This enhanced preparedness allows them to actively contribute to the continual transformation of mathematics education.

7.2 Limitations and future research

The research context of our study is limited to a specific demographic, “pre-service teachers” (PSTs) studying in Turkey. Expanding the scope of the research to include a more diverse range of participants could offer a more comprehensive understanding of the phenomenon being investigated. Moreover, the study’s reliance on self-reported data may have introduced response biases or inaccuracies. Future studies are warranted to broaden the scope of the present study and identify alternative approaches for preparing teachers to effectively integrate educational technology into their teaching and learning. This study advocates for a restructuring of the factors influencing integration and intent to optimize prospective teachers’ future use of educational technologies.

The UTAUT model incorporates several moderators, encompassing gender, age, experience, and voluntariness of use. Within this study, 205 PSTs took part, with an average age of 22.87 years. Unfortunately, due to the limited sample size, exploring the moderating effect of age was unviable. Furthermore, gender and seniority could be incorporated into the model as control variables. However, due to the imbalance between genders, we were unable to assess the moderating effect of these control variables. Additionally, the assessment of the moderating effects linked to experience and voluntariness was impeded by the overwhelming participation (99%) of individuals who reported voluntarily using at least one of the math applications.

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Data availability The data of the study will be made available upon reasonable request.

Declarations

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of Applied Ethics Research Center in Istanbul Medeniyet University, Human Research Ethics Committee, Istanbul, Turkey. Prospective teacher was informed about what they are supposed to be if they were voluntary to involve in the study. The participants of the study were guaranteed about anonymity to keep their data confidential. There was no deception or procedures that jeopardize participants’ physical or mental health. Informed consent was obtained from the participant of the study.

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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