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GAMIFYING TEACHER PREPARATION: EVALUATING PRE-SERVICE TEACHERS' ACCEPTANCE OF MINECRAFT EDUCATION IN DESIGN-BASED LEARNING

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Abstract:

Digital technologies are becoming increasingly central to education. Therefore, providing educators of the future with the skills to use innovative tools is crucial. Digital game-based learning (DGBL) platforms, for example Minecraft Education Edition (MEE), have transformative potential for classrooms in the 21st century. Nevertheless, numerous pre-teachers are unable to effectively integrate such platforms. This quantitative study examined the readiness of pre-service teachers to use MEE through the technology acceptance model (TAM). The study focused on the influence of perceived ease of use (PEOU), attitudes toward use (ATU), facilitating conditions (FC), and perceived usefulness (PU). This study involved 95 participants attending a Minecraft Teacher Academy workshop. Data were collected using a structured questionnaire and analysed using partial least squares structural equation modelling (PLS-SEM). The results revealed that FC significantly influenced PU and PEOU. The PEOU mediated the relationship between FC and ATU. These results highlighted the importance of supportive training environments that enhance ease of use and perceived value, which increase pre-service teachers' confidence and intention to incorporate MEE into teaching practices. This study contributed to the discourse on teacher education digital pedagogies and presented implications for designing professional development programmes and curriculum innovation in technology-enhanced learning.

Keywords:

Digital Games-based Learning, Minecraft Education Edition, Structural Equation Modelling, Pre-service Teachers' Readiness, Technology Acceptance Model

Introduction

Technological advancement is constantly shaping the economy, society, and culture, and presents new challenges and opportunities for world progress. Digital tools have emerged as an indispensable component of diverse learning needs in inclusive, active learning environments. Education digitisation and the introduction of electronic devices, such as computers, are increasing globally as technology use in classrooms increases (Tondeur et al., 2017). Accordingly, the educational system must be adapted to aid teachers in resolving the challenges of incorporating technology into the classroom (European Commission et al., 2017). The Malaysian Ministry of Education (2023) has promoted the Digital Education Policy (DEP) that highlights opportunities for integrating technology in traditional classrooms and transforming them into technology-enhanced modern learning spaces.

These educational reforms have inspired innovative pedagogical approaches, such as digital game-based learning (DGBL) with technologies, for example, Minecraft Education Edition (MEE). The DGBL increases the motivation and engagement of students by addressing diverse styles of learning and encourages mastery of content via active participation (Baltezarević & Baltezarević, 2025). Despite the potential benefits of DGBL, pre-service teachers' adoption of DGBL continues to be a major barrier. The adoption of these technologies is impeded by training that is limited, restricted digital tool access, and ignorance regarding the DGBL pedagogical applicability (Zainudin & Hashim, 2022). Furthermore, pre-service teachers may be challenged in merging theory and practice, where meeting the demands of the curriculum while applying teaching approaches that are creative and engaging can be difficult (Lee & Abd Rahman, 2021).

Teachers require the aid of programmes for professional development to address these barriers, acquire skills, and enhance self-confidence to successfully apply DGBL. Educators would be able to learn strategies for pedagogy and the technological skills to best utilise tools with training that is appropriate. Such usage of tools would enable a learning experience that is more interactive and student-centred, which would positively contribute to outcomes of learning and facilitate the growth of a populace ready for the future.

The MEE is a possible solution for bridging the gaps in the adoption of DGBL. The MEE DGBL platform presents learning spaces that are creative and appealing and is designed to improve skills of the 21st century, such as creativity, problem-solving, and collaboration, in a safe virtual learning environment (Shin et al., 2023; Panja & Berge, 2021). The MEE allows pre-service teachers to become accustomed to digital tools and technology while seeking real-world experience. This approach is crucial to developing the confidence and competence of pre-service teachers and enable their use of the tools in the classrooms. Furthermore, MEE enables an approach centred on the students and improves experiential learning, which enhances student engagement and teaching quality (Shin et al., 2023; Panja & Berge, 2021). Thus, the MEE is a learning experience that is interactive and immersive that facilitates students' participation in learning that is applied and experiential that reinforces the principles of STEM, encourages collaboration, and supports digital literacy.

The elements of the technology acceptance model (TAM) (perceived ease of use [PEOU], perceived usefulness [PU], and facilitating conditions [FC]) are major indicators of behaviour regarding the adoption of technology (Renny et al., 2013; Zahari et al., 2024). PEOU referred to the feeling of easiness using technology. PU referred to perception of usefulness in

productivity whereas FC meant the availability of the guidance in using the technology (Renny et al., 2013; Zahari et al., 2024). In this study, the significant aspect of pre-service teachers' acceptance of MEE was examined using the TAM. Additionally, the gaps in understanding digital pedagogies were bridged by investigating the external variables on pre-service teachers' willingness to integrate MEE as a tool for teaching. Furthermore, the results inform the design of effective teacher training programmes that capture motivational drivers and obstacles to the readiness to adopt digital game-based learning. Hopefully, these techno-pedagogical approaches will prepare current teachers for the 21st century classroom and inform pre-service teachers in teacher education programmes on the best implementation of technological devices in education.

Literature Review

The Technology Acceptance Model (TAM)

The TAM is one of the earliest and most influential models regarding technology adoption, which was first described by Davis in 1989. The TAM is derived from social psychology theory and describes technology acceptance in accordance with users' cognitive (PEOU and PU) and affective (attitudes toward technology use [ATU]) responses, which lead to behavioural intentions and actual technology usage (Marangunić & Granić, 2015). Other research domains have widely used the TAM, especially in education to assess educators' intentions to use new technologies (DGBL tools). Nonetheless, there is an emerging research gap among the pre-service teacher regarding TAM, especially in pre-service teachers' readiness to integrate game-based learning platforms, such as MEE, into their teaching practices.

The TAM is based on two main constructs: PEOU and PU. The PEOU refers to the extent to which users feel that using a specific technology will take little effort, while PU involves users' impressions about how technology can positively improve their productivity and performance (Davis, 1989). These constructs also affect ATU and the intention to use (ITU) (Scherer et al., 2019), which are followed by actual behaviours of use. For example, pre-service teachers who perceive the mobile edge environment platform as user-friendly and valuable for improving student engagement and learning outcomes would be more likely to implement it.

The TAM has been extended to include external attributes that lead to PEOU and PU. For example, enabling conditions strongly affect users' attitudes toward using new technologies (Abu-Al-Aish & Love, 2013; Venkatesh & Bala, 2008). These conditions are vital to whether teachers feel that they can introduce new innovations into education, such as mobile edge environments. While these areas have advanced, relatively little attention has focused on the influence of outer-contextual factors on pre-service teachers' acceptance of mobile edge environments. Bridging this gap is important as pre-service teachers are frequently lacking in the necessary training and support from their institution to integrate DGBL tools with confidence (Lehane et al., 2021).

A range of literature supports information technology (IT) acceptance in institutions of education through the TAM and includes explorations of education enhanced by technology, learning environments that are digital, and game-based learning (GBL) required by schools (Abu-Al-Aish & Love, 2013; Scherer et al., 2019). Instructors' and learners' adoption of the mobile educational environment has been analysed through the TAM, where such environments can improve creativity, collaboration, and critical thinking (Buchner et al., 2023).

Thus, the recommended contextual factors, which include curriculum alignment, infrastructure availability, and digital literacy levels, substantially moderate the relationship with PU or PEOU and technology adoption.

While much of the literature has investigated in-service teachers, pre-service teachers' specific challenges are rarely mentioned, for example, limited exposure to digital tools, lack of confidence, and challenges integrating DGBL with curriculum requirements (Singh & Suleman, 2022; Shin et al., 2023). Pre-service teachers are more challenged than other schooling levels, which may include improper access to specialised training programs based on digital pedagogies for teacher learners and the limited scope of the DGBL tools across their courses (Singh & Suleman, 2022; Shin et al., 2023). Such insights can bridge latent spaces through targeted interventions designed to help pre-service teachers with the demands of 21st century education. Specifically, students' intentions, which in this case refers to those in teacher training programmes, to accept mobile educational environments as digital literacy and the use of DGBL environments (such as MEE) becoming increasingly important, are of interest.

Barriers such as lack of training, low confidence using digital tools, and difficulties in contextualising such tools with the curriculum objectives may affect pre-service teachers' incorporation of DGBL in their practices (Shin et al., 2023). The TAM constructs continue to be especially relevant for identifying and addressing barriers to digital technology adoption. While the TAM is a proven conceptual model, most studies sampled in-service teachers, which ignored pre-service teachers' needs and barriers.

The TAM (Figure 1) comprises four main components: (1) ATU (actual user behaviour towards the new technology); (2) ITU (users' willingness to try new technologies); (3) PU (the subjective perception of users regarding the usefulness of technology that was newly adopted); and (4) PEOU (the effort expended by users in utilising technologies that are new) (Noor et al., 2022).

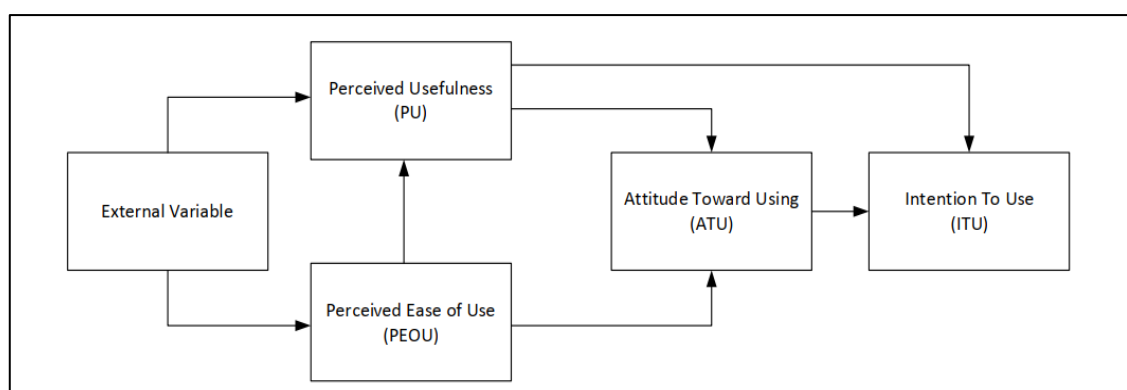


Figure 1: The TAM

Source: Davis (1989)

This study used the TAM to bridge these gaps and provide empirical insights into the external variable affecting pre-service teachers' readiness to adopt MEE. For example, how FC, self-efficacy, and ATU is affected by PEOU and PU, inform the creation of better teacher training programs were examined. The results could empower educators, administrators, and policymakers to develop professional development workshops, support systems, and resources

that collectively support pre-service teachers in embracing innovative instructional tools. This study is specifically significant in advancing the understanding of the elements related to pre-service teachers' DGBL adoption, which would better prepare future educators with the means to foster student-centred, interactive learning (Taherdoost, 2018; Buchner et al., 2023). This study bridged the gaps by examining the aforementioned factors to improve digital pedagogy training effectiveness and ensure better-equipped pre-service teachers for Malaysian and global education evolution due to rapid digitisation.

Educational Game-Based Virtual Environments and MEE

DGBL platforms, such as MEE, have generated interest as they can motivate students creatively and enable critical thinking. Previous studies emphasised the effectiveness of MEE in promoting active learning through problem-solving, collaborative learning, and experimenting in a virtual environment (Lee & Abd Rahman, 2021). Furthermore, MEE resonates with the aim of 21st century education, namely enabling students to interact with innovative concepts in this genre of simulation, such as designing sustainable cities, complex systems, and real-world challenges (Nordin et al., 2023).

The DGBL is an important shift in educational technology that indicates a paradigm that promotes engagement in learning. The DGBL is particularly relevant to remote, and hybrid learning and facilitates interaction and motivation among students, teachers, and parents (Lehane et al., 2021). Nevertheless, DGBL is not universally effective, where its success depends on the educational relevance of the selected games and their integration into the instructional process. "Serious games" are defined as computer or video games developed to educate the player and tailored to include game mechanics, such as adaptive challenges, reward systems, and narrative design, which allow their use as elements in developing effective learning experiences (Wang et al., 2022).

The MEE is an offshoot of the popular sandbox video game Minecraft that has become an important digital platform to support increased student engagement and learning opportunities. Classroom technology is typically used for direct teaching, whereas MEE fosters creativity, problem-solving, and collaboration, which present learners with design and construction opportunities in virtual worlds (Baek et al., 2020). The MEE is personalised for use in educational environments and its Code Builder and Book & Quill features permit teachers to guide and monitor the progress of students. Furthermore, students can use these to experience coding experiences that are increasingly visually rich, and teachers would be able to record and evaluate their development, which balances independence that is creative with learning that is structured (Baek et al., 2020; Bar-El & Ringland, 2020).

The MEE contributes to developing content that is curriculum-aligned and learning environments that flexible and student-centred. Educators have endeavoured to acclimate MEE to the classroom and convey STEM concepts that are challenging, enhance awareness of the environment, and mimic events in history. These approaches aid students' understanding of concepts that are theoretical with scenarios that are practical (Baek et al., 2020; Bar-El & Ringland, 2020). While MEE is promising, its successful integration relies largely on teachers' readiness and inclination to use it. As pre-service teachers typically have limited experience working with DGBL tools and restricted digital pedagogy input, their integration of these tools in teaching is extremely challenging (An & Cao, 2017).

While students accept digital tools (MEE) easily, teachers, and pre-service teachers specifically, frequently struggle to adapt to these technologies. As the move to DGBL dismisses conventional mindsets and pedagogy in practice regarding education, it becomes increasingly problematic for pre-service teachers with insufficient training and experience (OECD, 2016). Almost half the teachers with computers do not use them in regular teaching: one-third of teachers worldwide reported an average use frequency of less than once a week despite the numbers of computers available (An & Cao, 2017). This situation illustrates the value of professional development programmes, which have a clear goal that presents prospective teachers with the basic skills necessary for introducing digital resource into their classrooms. Another revolutionary case would be DGBL, which involves the game MEE to aid non-traditional learners explore subjects in-depth. Thus, these learners will be better equipped to face challenges in life. Yet, the effectiveness of such initiatives depends largely on the teachers, especially pre-service teachers' ability to incorporate these tools successfully as part of their instructional practices.

Closing the Pre-service teachers and Digital Pedagogy Gap

The MEE is a tool with transformative potential for student-centred learning. Nonetheless, pre-service teachers encounter systemic barriers to DGBL adoption, such as a lack of exposure to DGBL platforms in training, which is disadvantageous to the integration of such tools into classroom practice (Zainudin & Hashim, 2022). This issue is compounded by a near ubiquitous lack of confidence that originates from a lack of technical knowledge, with many pre-service teachers considering DGBL platforms to be complicated and not pedagogically aligned with curricular goals (Singh & Suleman, 2022; Baek et al., 2020).

The global trends mentioned in the Malaysian Digital Education Policy (Ministry of Education, 2023) have indicated an urgent need for digital transformation in education. Nevertheless, teachers' training programmes remain abstract and concentrate mainly on basic technical skills instead of their pedagogical integration (Becker & Park, 2011). This gap is especially harmful for tools, such as MEE, that bridge the divide between technical expertise and educators' curriculum-specific instructional design (Panja & Berge, 2021). Furthermore, the gap is widened by traditional approaches, which focus on the two critical components of effective technology adoption: creating positive perspectives regarding the innovation and creating abilities that will allow GBL tool transfer in multiple educational settings.

The educational schema that underpins the use of DGBL platforms are currently divided from their technical requirements. Given the lack of resources, mentoring, and access, educators frequently struggle to parallel GBL activities with educational learning outputs and outcomes, such as 21st century learning skills (critical thinking and collaborative problem-solving), and conducting formative and summative assessments (Shin et al., 2023). Furthermore, the perception of DGBL as supplementary rather than integral to instruction inhibits experimentation and results in a detrimental cycle of under-utilisation despite its proven advantages for engagement (Lehane et al., 2021). These challenges underscore the urgent requirement for systematically reforming teacher education programmes to enhance technical and pedagogical fluency.

Pre-service teacher programs are recommended to integrate immersive digital literacy, specifically in DGBL, to bridge this gap. The DGBL approach allows educators to design project-based learning using DGBL projects that present high potential to develop higher-order

thinking skills (critical analysis and creative problem-solving) through workshops that mimic actual classroom situations (Lehane et al., 2021; Buchner et al., 2023). Additionally, pedagogical mentorship by expert practitioners provides scaffolded guidance on how DGBL tools can be matched to curricular standards and how logistical challenges can be resolved (classroom management and differentiated instruction) (Zainudin & Hashim, 2022). Furthermore, modular training for creative capacity building in DGBL focuses on student-centred pedagogy, which enables educators to customise DGBL platforms to meet a range of learner types and the contextual constraints in which they operate.

Methodology

This study aimed to determine the feasibility of pre-service teachers using MEE in their teaching practices. Hence, a survey-based study was designed and involved participants who had attended a Minecraft Teacher Academy Workshop. The workshop emphasised practical experience for pre-service teachers using MEE in classroom instruction. A preview of the capability of pre-service teachers in using the MEE to design a house project explored evaluation tools throughout the MEE. The pre-service teachers experienced a learning environment that was cooperative, multiplayer, and project based. Furthermore, the pre-service teachers were involved in a workshop that provided a practical experience with the MEE features of world-building, such as specific blocks and tools, that allowed them to create learning spaces that were engaging and interactive (Buchner et al., 2023). The participants were aided by these experiences to prepare for the DGBL processes of creativity that were semi-structured, which necessitates digital capabilities.

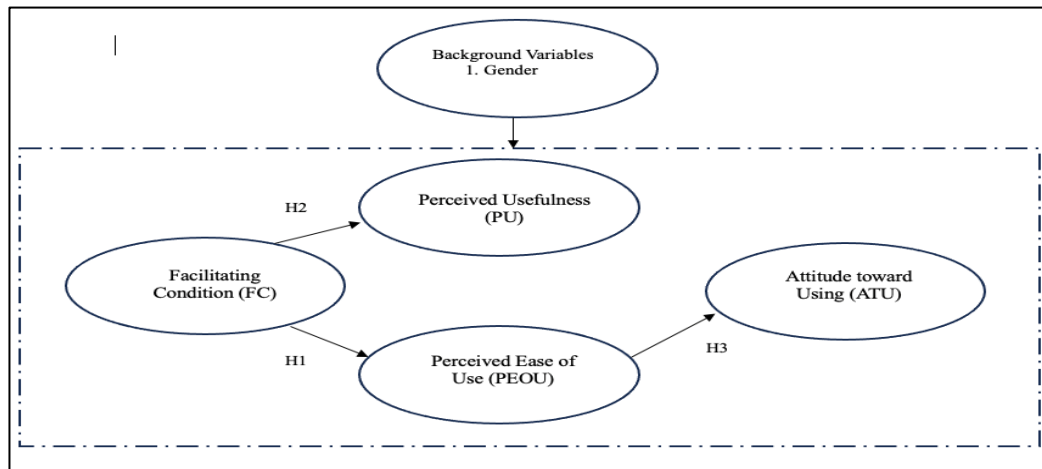
The sample involved 95 pre-service teachers from three institutions of teacher training in the states of Sabah, Ipoh, and Kelantan. Stratified random sampling was used to ensure sampling that was as representative and balanced as possible for the three states. Furthermore, the sampling enabled selection that was proportional and provided varied perspectives on the experience with DGBL while considering the pre-service teachers' diverse contexts of education (Creswell & Creswell, 2018). A Minecraft Teaching Readiness Questionnaire was used to obtain data. The questionnaire was distributed online using Microsoft Forms to facilitate the respondents' responses.

The TAM was used when developing the questionnaire to identify the primary factors contributing to the effectiveness of DGBL (PU, PEOU, and ATU) (Taherdoost, 2018; Scherer et al., 2019). These factors aided the determination of the respondents' readiness to use MEE into the classroom. Partial least squares–structural equation modelling (PLS-SEM) through SmartPLS was used to analyse the data. The PLS-SEM enables the assessment of complex models and the relationships among constructs (Hair et al., 2021).

Research Structure and Hypothesis

The link between PU, FC, PEOU, and ATU in the respondents' readiness to integrate MEE in the classroom was investigated. Figure 2 depicts the conceptual model used in this study and the four hypotheses as follows:

- H1: FC significantly influences PEOU in using MEE.
- H2: FC significantly influences PU in using MEE.
- H3: PEOU significantly influences ATU in using MEE.
- H4: FC has a positive intermediary effect on the relationship between PEOU and ATU in using ME.

**Figure 2: Hypotheses and Research Model**

Source: Authors' Work

Definition and Measurement of Research Dimensions

The four dimensions in this study were based on the TAM. Table 1 presents the operational definitions on the dimension in applying the MEE.

Table 1: Operational Definitions

Dimension	Operational Definition
FC	The ease and accessibility of MEE, which include the use of facilities, infrastructure, internet network in using the MEE.
PU	Pre-service teachers' believe that MEE is extremely helpful for teaching.
PEOU	Pre-service teachers believe that MEE is easy to use.
ATU	Pre-service teachers' belief, feeling, affective, and intention in using MEE.

Source: Authors' Work

Data Collection and Analysis

The Minecraft Teaching Readiness Questionnaire adapted Fauzi et al.'s (2021) questionnaire. The questionnaire consisted of two parts: the respondents' demographic data and the TAM (three PEOU, two PU, two ITU, three ATU, one PV and two FC statements) (Table 2).

Table 2: Minecraft Teaching Readiness Questionnaire

Dimension	Statement
PEOU	Minecraft is easy to learn.
	It is easy to master Minecraft skills.
	Minecraft is easy to use.
PU	Minecraft is useful in teaching to aid students' understanding.
	Minecraft will make my teaching enjoyable.
ATU	I like to learn in classes that incorporate Minecraft.
	I like using Minecraft.
	I know how to use Minecraft.

FC

I have the facilities to support Minecraft use at home (computer, handphone, and the Internet).

I have the facilities to support Minecraft use at my learning institution (computer, handphone, and the Internet).

Source: Adapted from Fauzi et al. (2021)

Results and Discussion

The increasing emphasis on digital education and DGBL tools underscores the relevance of the TAM in studying pre-service teachers' readiness to adopt such technologies. This study aimed to bridge these gaps using the TAM and present empirical insights into the factors that form pre-service teachers' readiness to adopt MEE as an educational tool. The TAM emphasises key constructs (PEOU and PU) and presented a framework that is structured for exploring the respondents' perspectives and connections with digital technologies. The FC (access to resources, institutional support, and self-efficacy) shapes these constructs. The respondents' motivation and attitudes regarding the adoption of a DGBL platform were significantly influenced by these aforementioned factors (Taherdoost, 2018; Buchner et al., 2023). For example, teacher education programmes that include modules for practical training can positively influence PEOU and PU, as pre-service teachers will acquire confidence and competence to use MEE effectively to design learning environments that are creative and centred on the learner.

The complex inter-relationships among latent constructs and their manifest indicators are assessed using SEM. The model emphasises the perspectives of pre-service teachers' regarding classroom-adapted technologies through the TAM, which highlights the acceptance of technology, specifically DGBL. The SEM diagram provides a complete framework for investigating the shared methods for DGBL platform implementation in training settings for teachers. The SEM uses the PEOU, PU, and ATU constructs to demonstrate the interactive effect of pre-service teachers' attitudes and external stimuli (FC) on their intention to adopt MEE. The SEM diagram in Figure 3 captures the relationships between the constructs influencing pre-service teachers' adoption of DGBL.

The relationships delineated in the SEM diagram (Figure 3) suggested that FC, PEOU, PU, and ATU shape behavioural intention to use digital tools in teaching. The results highlighted the significant effect of FC on PEOU and indicated that support from teacher training facilities positively influenced the respondents' PEOU regarding MEE. The respondents' PU and PEOU regarding MEE increased when they received facility support. Furthermore, PEOU significantly mediated the relationship between FC and ATU, which supported PEOU as a key variable that indirectly explains the ATU the MEE (Marangunić & Granić, 2015).

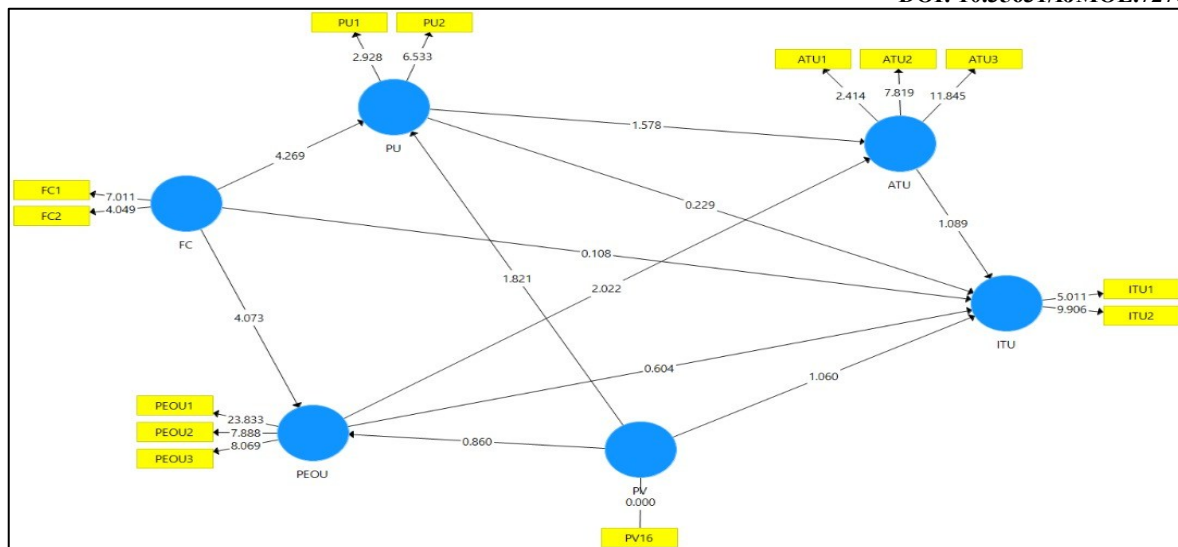


Figure 3: The SEM Diagram

Source: Authors' work

The latent variables in the SEM Diagram (Figure 3) are represented by the blue circles, which denote abstract concepts that cannot be directly measured. Instead, these concepts are inferred by measuring observable indicators. For example, the PEOU described the respondents' perceived degree of freedom in using MEE as extremely easy, and PU involved the respondents' perception that MEE improved teaching and learning. The ATU indicated the respondents' favourable or unfavourable approach to MEE. In addition, external constructs (FC) were external enablers that substantially affected the core TAM constructs.

The observed variables (yellow rectangles) in the model were the measurable indicators of the latent variables. These observed variables were data points for estimating and confirming the relationships in the SEM. The PEOU1, PEOU2, and PEOU3 measured the system ease of use, while PU1, PU2, and PU3 indicated its PU. The model displayed causal relationships as unidirectional arrows between constructs. The path coefficients associated with these arrows indicated the strength and significance of these relationships. For example, PEOU and PU were strongly and positively related, which indicated that the PEOU strongly enhanced the respondent's PU. The PU substantially influenced ATU. Furthermore, constructs external to the model (FC) positively influenced PEOU and PU, which proved that FC was a crucial enabler in technology adoption.

The analysis established that this measurement model satisfied the requirements for internal consistency reliability, convergent validity, and discriminant validity. The inter-item and item total correlation (discriminant validity) cooperatively established the reliability (Cronbach's alpha: 0.75–0.86; composite reliability: 0.88–0.93). These values were higher than the limits of acceptance of 0.7 and 0.6 for Cronbach's alpha and composite reliability, respectively (Hair et al., 2021), thus demonstrating that the items within each construct could be considered consistent and reliable. The Fornell-Larcker criterion confirmed the discriminant validity, as the square root of average variance extracted (AVE) per construct (between 0.85 and 0.93) exceeded its bivariate correlation with other latent variables. This output indicated that the value was sufficient for identifying discriminant validity (Henseler et al., 2015) and demonstrated that each construct was separate and were responsible for different variances.

Outer loadings and the AVE were used to verify convergent validity. All indicators had outer loadings > 0.7 (none exceeded the acceptable range) and each construct had AVEs > 0.5 , which suggested that they opposed the recommended benchmarks. This result indicated that more variance was explained with the indicators of each construct than with its measurement error, thus confirming that items were correctly designated to their associated constructs (Hair et al., 2021).

The structural model demonstrated high and positive path coefficients, which indicated that the relationship predicted among constructs was reasonable. The analysis identified four significant paths: PEOU was significantly positively affected by FC ($\beta = 0.628$; $t = 3.708$; $p < 0.05$), which suggested that the respondents considered MEE easier to use when they perceived that resources were adequate, and support was available (Table 3). The FC positively affected PU ($\beta = 0.696$; $t = 4.209$; $p < 0.05$), which indicated that the PU of MEE for teaching was greater when more sufficient resources and support were provided (Hair et al., 2021). The PEOU significantly and directly affected ATU ($\beta = 0.516$; $t = 2.038$; $p < 0.05$), which demonstrated that respondents with easier MEE usage would have more positive attitudes towards using MEE in their teaching practice.

The model demonstrated an indirect effect of perceived value on ATU ($\beta = 0.324$; $t = 2.351$; $p < 0.05$), which indicated that PEOU was an important mediator in clarifying the effect of perceived value on the respondents' attitudes towards using MEE. This result reiterates the fact that ease of use was positively related with the respondents' intention to adopt MEE. This study obtained evidence supporting the direct effect of FC on PEOU and PU, and the strong influence of both constructs on the respondents' attitude towards MEE. The PEOU is important and a valuable variable for future studies as it mediates the intentions that have positive effects in the model. Such results demonstrate that sufficient resources and support are needed to promote technology integration in these areas, specifically through processes that improve pre-service teachers' perceptions of ease of use and usefulness when utilising such tools, as MEE.

Table 3: Direct and Indirect Effect Path Coefficients

Hypothesis	Relationship	β	t-value	p-value	Confidence interval (BC)		Result
					LL	UL	
H1	FC $\rightarrow$ PEOU	0.628	3.708	0.000	-0.050	0.837	Supported
H2	FC $\rightarrow$ PU	0.696	4.209	0.000	0.233	0.926	Supported
H3	PEOU $\rightarrow$ ATU	0.516	2.038	0.042	-0.032	0.934	Supported
H4	FC $\rightarrow$ PEOU $\rightarrow$ ATU	0.324	2.326	0.020	-0.025	0.590	Supported

Note: BC = Bias-Corrected; LL = Lower Limit; UL = Upper Limit of 95% Bootstrapped Confidence Interval

Source: Authors' Work.

The results demonstrated that FC significantly and positively affected PEOU and PU and highlighted the urgent need for institutional support in form, context, and provisioning. Pre-service teachers should be able to use MEE effectively. The MEE involves self-space, self-improvement and self-perfection. For example, the path coefficients 0.696 (FC $\rightarrow$ PU) and 0.628 (FC $\rightarrow$ PEOU) indicated that adequate supporting infrastructure would enable the respondents to perceive MEE as acceptable-enhancing and acceptable-optimising. This result was supported by Shin et al. (2023), who reported that comprehensive support systems are required to encourage digital pedagogy adoption.

Table 3 demonstrates that H1 was supported. Hence, FC promoted the respondents' attribute of MEE usability. Aligning with the TAM, FC are external enabling factors that minimise the complexity associated with digital tools, thus enhancing positive perceptions (Venkatesh & Bala, 2008). The significant t-value (3.708, $t > 1.96$) and extremely low p-value ($p < 0.05$) suggested that FC contribute positively to the respondents' PEOU regarding MEE. The effect was moderately strong ($\beta = 0.628$), which was also demonstrated in the confidence interval (BC): lower = -0.050 and upper = 0.837. Ottenbreit-Leftwich et al. (2018) reported that institutional support or mentorship are key facets in granting pre-service teachers the confidence and ability to utilise educational technology for transformative learning.

The similar results for H2 demonstrated the significant relationship between FC and PU. The high path coefficient ($\beta = 0.696$) and significant t-value (4.209, $t > 1.96$) with $p < 0.05$ indicated that FC positively affected PU. Hence, H2 was supported. The results suggested that FC are important for pre-service teachers regarding the level of usefulness of MEE in improving teaching and learning outcomes. The literature has reinforced the need for sufficient training and resource access, which allows pre-service teachers to value the pedagogical assets of DBGL devices (Panja & Berge, 2021). The high levels of FC and PU demonstrated that significant investments in teacher training programmes are needed, as provision without proper professional development leads to failed IT implementations in schools (Buchner et al., 2023). This result also demonstrated how pre-service teachers' value tools that match their specific teaching goals along with achieving the best possible learning outcomes. This result aligned with earlier studies (Buchner et al., 2023), which highlighted the important role of PU in decisions to adopt technology in education. Pre-service teachers who consider MEE a useful tool in their teaching toolbox are likelier to incorporate it into their practices, especially in DGBL situations. Furthermore, this result demonstrates that pre-service teachers who are appropriately provisioned and supported will believe that MEE is a viable and powerful tool for improving teaching and learning outcomes. Furthermore, the confidence interval of 0.233–0.926 did not encompass zero, which confirmed the reliability of this result.

The H3 was also statistically significant. The t-value (2.038, $t > 1.96$) and p-value ($p = 0.042$) suggested that the hypothesis was supported, particularly by $p = 0.042$, and the path coefficient ($\beta = 0.516$) demonstrated a moderate influence. The strong association between PEOU and ATU ($\beta = 0.516$, $p = 0.042$) was relevant to the pairing of simplicity in technological tools with the adoption of pre-service teachers' positive attitudes ($p = 0.042$). When MEE is perceived as user-friendly, pre-service teachers are more likely to adopt it enthusiastically in their classrooms. Accordingly, this relationship indicates that pre-service teachers who believe that MEE is easy to use are more likely to have a positive attitude regarding its adoption. This result was consistent with Lehane et al. (2021), who stated that PEOU affects users' attitudes directly, especially in scenarios incorporating novel digital tools. This result was consistent with the TAM, which states that behaviour-friendly technology reduces barriers to its adoption. Despite this strong association, the confidence interval lower bound approached zero, which indicated the importance of continuous improvements to user interface design and usability to enhance this relationship. Furthermore, the weak confidence interval indicated that improvement may be required, where pre-service teachers with prior digital literacy experiences or exposure to similar tools may provide different responses. Thus, pre-service teachers who consider MEE freely usable would be more likely to adopt a favourable attitude towards using it for teaching.

The result for H4 supported the indirect relation of FC and ATU via PEOU. The t-value (2.326, $t > 1.96$) and p-value ($p = 0.020$) ($\beta = 0.324$) reflected the degree of the path coefficient, where the p-value of < 0.05 ($p = 0.020$) indicated that the mediation effect reached significance. The mediating role of PEOU between FC and ATU was accepted with $\beta = 0.324$, $t = 2.326$, and $p = 0.020$ (moderate mediation effect). The FC as an indirect enabler ($\beta = 0.324$) and the mediating effect of PEOU on FC and ATU ($p = 0.020$) indicated that external support is important, but this function is optimal if pre-service teachers believe that MEE is easy to use. This outcome underscored the utility of PEOU as a mediator and demonstrated that FC increased favourable attitudes regarding MEE indirectly by increasing its PEOU.

These results highlighted the importance of holistic support systems in teacher education, which provide technical assistance and use approaches to build self-efficacy and confidence to support realistic feedback (Singh & Suleman, 2022). The results suggested that institutional interventions, which include training programs and technical support, must target resource provision and user confidence through simplified interfaces and usable demonstrations. Empowerment with practical experience could support bridging the gap between institutional support and personal acceptance of technology (Panja & Berge, 2021). This aspect highlighted the importance of FC in contributing to ease of use and in encouragement and positive attitude towards MEE via PEOU. Furthermore, the confidence interval ($BC = -0.025$ to 0.590) supported a mediated relationship.

The results strongly supported the hypotheses and demonstrated that FC are vital in shaping pre-service teachers' PEOU and PU which strongly influence their attitudes regarding MEE adoption. These results underlined the relevance of addressing external enablers (support and resources) to enhance the adoption of DGBL tools in teacher education programmes. Furthermore, the results emphasise the necessity of specific training programs to improve ease of use and pre-service teachers' attitudes to facilitate the effective incorporation of digital tools in the classroom. Most importantly, the model emphasised that positive perceptions and attitudes significantly translate into a stronger attention intention to use MEE. Addressing these interconnected elements would empower teacher training programmes to equip pre-service teachers more effectively and enable them to implement innovative tools and transform their classrooms from outcome-focused arenas into thriving, student-centred spaces.

The results supported the explanatory nature of the TAM constructs into the general premise of MEE implementation among pre-service teachers. The FC are important in determining the PEOU and PU, which determines attitude and behavioural intention. This aspect can aid in developing an innovation among future educators and ensure that they have the skills to become innovative and forward-thinking in their educational practices by overcoming the lack of confidence and insufficient training.

The results hold important implications for policymakers and educators working to close the gap between technology availability and its effective implementation in classrooms. Additionally, the TAM provides a robust framework for addressing systemic barriers to digital technology adoption in teacher training. Insights derived from the TAM can inform the design of professional development programs that encourage positive attitudes toward technology use, enhance digital literacy, and create supportive environments for pre-service teachers. This approach would address immediate challenges and equip pre-service teachers with the skills

and mindsets needed to integrate innovative tools into their future classrooms (Zahari et al., 2024).

The SEM results indicated that FC, PEOU, and PU are important predictors of pre-service teachers' attitude regarding MEE and their intention to adopt it. The DGBL tools are designed to render the learning process more engaging and interactive and are becoming increasingly popular in academia. Despite the complementary strengths offered by game-based tools offer, they have not been fully incorporated into curricula. Additionally, implementing user-friendly designs and interactive elements in MEE can enhance its PEOU, which would facilitate higher usage among pre-service teachers.

The results highlighted the importance of addressing external and internal factors affecting technology adoption in teacher education programs. Training that enhances self-efficacy and positive attitudes towards digital tools should be complemented by FC (mentorship and technical support). The intention is not to convince all pre-service teachers to adopt MEE but lead them through a useful idea kit and clear approach to discovery through new tools. These tools need not be intimidating or overwhelming but should enhance engagement and importance in the classroom. This study addressed the research gaps and contributed to the TAM literature, specifically targeting pre-service teachers, whose level of technological acceptance is less studied compared to in-service teachers. The results demonstrated that external factors (FC) are not directly associated with behavioural intention but are indirectly associated through PEOU and PU. This comprehensive perspective can guide appropriate frameworks for digital pedagogies that account for pre-service teachers' context and challenges.

Conclusion

This study confirmed that FC (technical support and motivation) are pivotal in shaping pre-service teachers' PEOU and PU regarding MEE. These perceptions influence pre-service teachers' readiness to adopt digital tools in design-oriented teaching. Embedding DGBL environments in teacher education curricula is promising for strengthening pedagogical engagement and technological competence. Importantly, MEE exemplifies a platform that embodies technology and design education goals, where it enables "learning by doing", fosters creativity, and develops design thinking capabilities. Educational policymakers and curriculum designers can sustain this momentum by considering the integration of open-ended digital environments into national teacher preparation programs and ensuring alignment with broader goals of innovation, STEM integration, and digital fluency in 21st century education.

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