

PAPER

From Access to Achievement: A PLS-SEM Analysis of Mobile Learning Engagement in Chinese Higher Education

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ABSTRACT

This study investigates the adoption, effectiveness, and pedagogical impact of mobile learning applications on the academic development of college students in China. Specifically, it examines how perceived ease of use, perceived usefulness, instructor support, and access to mobile technology influence academic outcomes, with mobile learning engagement acting as a mediating factor. A quantitative research design was employed using survey data collected from 234 college students across various Chinese universities. Validated scales were adopted from prior studies to measure all constructs. SmartPLS 4.0 was used to analyze the structural relationships through partial least squares structural equation modelling (PLS-SEM). Results confirmed that perceived ease of use, perceived usefulness, instructor support, and access to mobile technology all have significant positive effects on students' academic development. Furthermore, mobile learning engagement was found to mediate the relationships between these predictors and educational development, reinforcing its central role in digital learning environments. This study contributes to the growing body of literature on mobile learning by integrating elements from the technology acceptance model (TAM), Constructivist Learning Theory, and Engagement Theory. It offers practical and theoretical implications for educators, app developers, and policymakers aiming to foster meaningful student engagement and academic growth through mobile learning platforms.

KEYWORDS

mobile learning applications, academic development, mobile learning engagement, instructional support, technology adoption

1 INTRODUCTION

With the pace of the digital change gaining traction in our times, the adoption of mobile technologies in higher education has gained momentum, particularly in the example of China, where the national government has placed the development of

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innovative teaching and digital learning environments at the forefront of its agenda. The presence of mobile internet and smartphones has led to the view that mobile learning applications should be considered as an inexpensive and scalable method of supporting the learning process of students [1]. They offer diverse functions such as interactive course content, formative quizzes, discussion forums, and individualized learning paths [2]. A country like China has initiatives like the Smart Education of China project that has seen universities embrace mobile-based applications that not only have facilitated education inclusiveness but also pedagogical innovation with the aid of technology [3, 4]. Although such efforts have been made, the effectiveness of learning applications and their real usage still varies according to the region and university, which is why researchers seek to understand the psychological, technological, and environmental factors that influence the use of these applications by students [5]. In addition, Chinese higher education is facing increasing pressure to provide students with self-regulated learning abilities and digital literacy for the knowledge economy, so studying mobile learning environments is particularly pertinent [6].

Current empirical research brings strong evidence that factors influencing technology acceptance, specifically perceived ease of use and perceived usefulness, significantly contribute to students' intention to use educational apps as well as their learning results [7]. For example, several studies using the technology acceptance model (TAM) have shown that when students find a mobile app easy to use and helpful in studying, they are likely to utilize it regularly and gain academic advantages [9]. Within the Chinese context, studies have also established that perceived ease of use has a significant impact on the intention of students to use mobile learning platforms such as Super Star Learning, which are popularly utilized throughout Chinese universities [10]. Similarly, perceived usefulness has been related to higher levels of student satisfaction and higher motivation, and students have a higher probability of achieving higher academic outcomes, as students tend to internalize the relevance of these tools towards the achievement of their academic goal [11]. Combined, such findings support the idea that self-perceptions of the learning technologies among students are important factors to consider when defining their learning behaviors and academic performance.

Moreover, the studies have gradually highlighted the importance of contextual and social factors such as instructor support and access to mobile technologies in determining the learning process in students. One example is the support provided by an instructor, which has been found to raise students in terms of confidence in the usage of learning technologies, participation, and subsequent improvement in engagement and satisfaction [12]. In China, where teaching and learning practices are deeply rooted in Confucian values of teaching, the role of the instructor in facilitating and supporting the use of mobile learning tools in classroom activities also becomes more important [13]. In the meantime, the availability of mobile technology, both in terms of hardware and the ability to connect and be connected, and institutional infrastructures, are key factors in determining the success of learners in the digital learning setting. According to research carried out by [2, 14], students who have increased access to mobile phones and who have good Internet access demonstrate increased engagement and improved learning outcomes. Such empirical trends emphasize the multidimensionality of mobile learning and the need to have an integrative model that would take into consideration the perceptions of technology, teaching support, and infrastructure in the process of analyzing the learning growth.

Still, despite the growing amount of research, no one has managed to fill in some very important gaps, particularly in the Chinese educational background. To begin with,

in as much as the TAM has been widely applied to explore the perceived ease of use and perceived usefulness, many studies have omitted these two variables as having direct impacts on the student performance without a close study of the mediating effects that transform technology perception to actual academic performance [15]. For instance, little has been studied regarding how mobile learning participation acts as a behavioral bridge between students' initial attitudes towards mobile applications and their academic achievements [16]. The lack of such mediation analysis restricts understanding why and how mobile apps can or cannot support learning achievements [17]. Additionally, there is less concern regarding the interplay between instructor guidance, technology access, and student engagement activities in mobile learning contexts, particularly in collectivist cultures such as China's, where social influence and teacher support are significant [18].

Secondly, the majority of existing studies in China tend to concentrate on individual platforms or assess disconnected variables, hence without a comprehensive framework that brings together user perceptions, contextual support, and behavioral engagement under one model. While research has investigated the effect of mobile learning on discrete skills like reading or the teaching of language [19], there is limited research that associates the more general construct of academic growth with these varied influences within a theoretically sound model. In addition, demographic and institutional variation in adopting mobile learning—e.g., urban vs. rural universities or first-rate vs. second-rate institutions—is usually not taken into account [20]. That limits the applicability and generalizability of delivered findings. Therefore, it is clear that integrative empirical research that will examine the direct association between the variables of technology and learning outcomes, as well as the mediating role of mobile learning involvement in Chinese higher education, is needed.

The study expects to fill gaps in existing empirical studies and enhance the knowledge on mobile learning in Chinese higher education by analyzing the interconnecting relationship between perceived ease of use, perceived usefulness, instructor support, mobile technology availability, mobile learning engagement, and academic growth of students. More specifically, the study will plan and analyze a conceptual framework that will unite cognitive, environmental, and behavioral variables within a mobile learning setting. The main focus is to understand not only whether these factors influence the process of academic development, but more importantly, how they influence it with the mediating role of student involvement in mobile learning technologies. With mobile learning reshaping the educational landscape, it is necessary to spend some time to go beyond the superficial analyses and examine how digital tools can influence learning behavior and learning outcomes.

Even though the study is framed within the framework of the Chinese higher education system, the issues that are discussed fall in a broader international discussion of mobile learning ecosystems as sources of digital equity and pedagogy-mediated technology-based innovation. According to such international standards as the ICT Competency Standards of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the DigComp project by the European Commission, and the Digital Education Outlook published by the Organization of Economic Cooperation and Development (OECD), user-centered design of technologies, facilitation by educators, and meaningful engagement of learners are the priorities. These world plans underline the fact that the mobile learning uptake does not solely depend on the technological affordance, but it also depends upon a number of cultural, social, and institutional circumstances. Contextualizing the study in such a broader context will result in making it more pertinent since the Chinese case is not an exception of such

a transnational issue on the degree to which higher education systems worldwide have adopted mobile learning to enhance the development of academic processes.

This study has an important theoretical and practical implication in the development of mobile learning in Chinese higher education. Theoretically speaking, the study adds to the currently existing discussion on educational technology by synthesizing the ideas of TAM, the theory of engagement, and contextual support frameworks into a single conceptual framework that discusses both direct and mediated pathways to academic development. It gives a more comprehensive insight into how mobile learning tools work in a rich learning system. Practically, the study can be useful to university administrators, instructional developers, and policymakers in identifying the most significant factors of student academic performance regarding mobile learning. Specifically, it underscores the necessity to ameliorate the technological component of the learning applications, as well as the support system and support measures surrounding its implementation. With the expanding dependence on digital platforms in post-pandemic China, the study provides valuable insights for developing inclusive, effective, and interactive mobile learning plans that are aligned with national educational priorities and institutional capabilities.

2 LITERATURE REVIEW

Mobile learning research has gathered pace throughout the world, with major contributions from Europe, South East Asia, North America, and Africa, which document similar determinants for the adoption of technology, such as student autonomy, teacher facilitation, and digital infrastructure. Studies conducted in Finland, Singapore, Canada, and South Korea emphasize that successful ecosystems for mobile learning depend on the combination of student-centered design, instructor scaffolding, and equitable access. Integrating these international studies offers a wider empirical base for the proposed framework and locates the current work in wider debates on digital learning readiness and technology-supported pedagogy in other parts of the world.

2.1 Perceived ease of use of learning apps and students' academic development

Perceived ease of use is the degree to which a person feels that applying a given technology will be effortless [20, 21]. In educational technologies, particularly learning applications, this aspect plays a pivotal role in influencing students' participation and inclination to adopt such tools as part of their academic practice [22]. Academic progress refers to the enhancement of knowledge gain, critical thinking, learning effectiveness, and general performance by students in learning activities [23, 24]. Learning applications that are developed with easy-to-use interfaces, simple navigation, and reduced cognitive load can promote more efficient learning experiences and lower the technological boundaries to educational participation [8]. The easier it is for students to use educational apps, the higher the chances they will check out their features, use them regularly, and incorporate them into their studying habits, which eventually leads to their academic advancement [6, 25]. Empirical findings have validated the relationship between perceived ease of use and educational achievement. [10, 26] found that ease of use significantly influences

students' continued intention to use e-learning systems, which is associated with better learning outcomes. Similarly, it is reported that perceived ease of use positively correlates with satisfaction and learning performance among university students using learning platforms [27]. These results concur with the assumptions of the TAM, in which ease of use is a determining factor for behavior intention and system usage.

H1: Perceived ease of use of learning apps has a significant positive effect on students' academic development.

2.2 Perceived usefulness of learning apps and students' academic development

Perceived usefulness refers to the extent to which a user perceives that the use of a given system or tool will improve their work or task performance [28]. In schools, students believe that learning apps can enhance their academic achievement, learning effectiveness, or subject mastery. It is a dominant factor in determining whether or not students will use educational technology and use it regularly [29]. As students perceive that an electronic tool can offer helpful assistance in the realization of academic objectives, for example, through improved comprehension, interactive exercises, or prompt feedback, they will be more likely to use it actively [23, 30]. This way, perceived usefulness turns into a motivational construct that supports technology integration into routine academic conduct. Several empirical investigations verify the significant predictive contribution of perceived usefulness towards learning outcomes. Nuryakin et al. [31] discovered that the perceived usefulness of the students heavily determines their behavioral intention to use the learning technologies, which in turn impacts their learning performance. Furthermore, [32, 33] demonstrated that perceived usefulness had the highest influence among all factors in predicting the success of mobile learning systems within higher education. When learning applications are viewed as almost valuable for academic work, students tend to integrate them into their study patterns, thus improving their learning achievements.

H2: Perceived usefulness of learning apps has a significant positive effect on students' academic development.

2.3 Instructor support for mobile learning and students' academic development

Teacher support in mobile learning settings can be defined as the teaching, motivation, and pedagogical guidance that teachers provide to learners so that they can make use of mobile learning technologies in an effective manner [12]. This includes such elements as instruction scaffolds, appropriate communication of standards, regular feedback, and integration of mobile apps into formal teaching practice [18]. In this case, academic progress can be defined as the improvement of learning attainments, intellectual capacity, and scholarly drive of students [34]. The attitude of the students towards educational technology and their actual behavior is mainly influenced by the role of the instructors. When the instructors create a positive environment that encourages mobile learning and provide follow-up, students will feel encouraged and confident to apply learning applications to

improve their academic competence [16, 35]. Empirical studies have highlighted the roles of teacher support to inform persuasive mobile learning experiences. It was determined that teacher engagement positively impacts the beliefs that students have about the usefulness and usability of mobile learning tools, which subsequently enhance the learning outcomes [13]. Similarly, [36] emphasized the fact that students working with the help of mobile learning platforms are more interested in using this kind of technology when teachers serve as a model and provide both technical and academic support. These findings show that professor support does not only facilitate technological adoption but also facilitates the learning value of mobile applications.

H3: Instructor support for mobile learning has a significant positive effect on students' academic development.

2.4 Access to mobile technology and students' academic development

The term access to mobile technology is used to denote the convenience and the practicability of accessing mobile phones, the internet, and applications of learning that are needed in mobile-assisted learning. It includes not only physical access (e.g., tablets, smartphones, data plans) but also digital access (e.g., access to apps, learning management systems, and learning material) [20]. With stable and equitable access, students will have an opportunity to participate in mobile learning processes, communicate with other students, and use digital resources to develop education [23, 37]. The potential of mobile learning cannot be fulfilled when there is inadequate access, particularly in a setting with scarce resources [14]. There exists empirical evidence that supports the claim that access to mobile technology is a starting-point facilitator of academic benefits of digital learning. As Sani and Ratri [38] point out, students who have uninterrupted access to the internet and the mobile gadgets are reported to be more engaged and satisfied in blended learning environments. In the same vein, Shortt et al. [29] demonstrated that the opportunity to have more access to mobile technologies correlates positively with the learning outcomes of students, particularly when accompanied by intelligently constructed instructional content. These findings point to the fact that access is not merely a logistical issue but a determinant of whether students can utilize mobile learning to the full to improve educational progress.

H4: Access to mobile technology has a significant positive effect on students' academic development.

2.5 Mobile learning engagement as mediator

Mobile learning engagement defines the level of student engagement, which is behavioral, emotional, and cognitive, in the active use of mobile-based applications and tools as learning ones [1]. This construct reflects several attributes of sustained attention, engagement, motivation, and determination of academic activities assisted with the help of mobile technologies by students. Although a perceived ease of use is the extent to which students hold that a learning app is easy and simple to use [2], its influence on academic advancement does not necessarily go directly.

Rather, it is the actual interaction with the tool that is performed as a mediating factor that directs this perception to a significant academic result. The previous research has shown that the usability is a significant factor that boosts the desire of students to use the digital tools, which consequently raises the engagement rates [5]. In addition, Budiarto et al. [6] have shown that as long as students consider mobile apps easy to use, they tend to be willing to develop positive emotional reactions and dedicate regular effort to academic interactions on the platform. On the same note, [10] discovered that the indirect effects of performance outcomes due to the perceived ease of educational technologies were by way of increased levels of cognitive and behavioral engagement. Since the processes of academic development are the processes of acquiring knowledge, critical thinking, and persistence in the work, one can suppose that it is only with the significant involvement of mobile learning tools that the ease of use can be transformed into academic benefits.

H5: Mobile learning engagement mediates the relationship between perceived ease of use of learning apps and students' academic development.

Although it is observed in previous literature that the perceived usefulness has a positive impact on the academic growth of students [34], more sophisticated studies indicate that the intensity of the mentioned association might be contingent upon the degree of learner engagement with the mobile platform. Mobile learning, the cognitive commitment, the interpersonal, and the interactive aspect of students in mobile-based educational activities can be the medium through which perceived usefulness can assert its pedagogical impact [18]. Studies conducted by Fan and Wang [22] indicate that those students who view mobile learning as an advantage will tend to spend more time engaging with course content, discussing, and taking tests on the mobile apps. Furthermore, this has been demonstrated by the works of [3, 39] that found that student engagement is a crucial mediator between technology-related perceptions and learning outcomes, and that usefulness perceptions cannot be effective on their own without active engagement. Therefore, the engagement of mobile learning may be theorized as the behavioral form of the student's confidence in the usefulness of an app that results in the transfer of abstract perception into concrete academic achievement.

H6: Mobile learning engagement mediates the relationship between perceived usefulness of learning apps and students' academic development.

Empirical studies have indicated that teacher support is a very important factor in improving the learning outcomes of students, as it encourages an environment where technology adoption and continued engagement become possible. According to [40], those students perceiving instructional support at high levels get more motivated to engage in mobile-based learning and demonstrate more persistence in using educational apps. Likewise, Saleem et al. also found that instructor guidance plays a central role in motivating and engaging students in mobile learning space [41]. Nevertheless, the direct influence of teacher support on academic growth might not be as complete a picture as it can be. Rather, the availability of instructor support can have an impact on the student outcomes by means of their interaction with the mobile learning in itself. With encouragement, feedback, and structured learning experiences delivered with the help of mobile apps, students are more susceptible to engaging in such applications, which results in more emotional

and cognitive engagement [42]. It is important to note that [43] argue that such engagement is one of the key ways external supports determine academic outcomes. Additionally, Hazaymeh et al. [13] also showed that technology-related engagement behaviors mediated the role of instructional support on academic success significantly [36]. Based on these results, it is reasonable to presume that instructor support has a beneficial effect on the learning process of students, as it increases their interest in mobile learning.

H7: Mobile learning engagement mediates the relationship between instructor support for mobile learning and students' academic development.

Although access to mobile technology is an important facilitator of digital learning, previous studies indicate that the educational effect of access is not inherent and, in most cases, depends on the extent to which students utilize the technology that is made available [44]. Students who had increased access to mobile resources showed better academic performance [45]. Nevertheless, they had a strong influence on their interaction with mobile learning environments [46]. Similarly, [47] have found that access alone did not predict academic success, unless the students engaged in the tools provided in an active manner (taking quizzes, discussions, and learning the content) to do so. This is also in line with [10], who demonstrated that the usefulness of mobile learning was enhanced when students converted access to meaningful, repeated interaction. That is to say, the access enables the opportunity, though the student engagement is the one that brings to life the learning potential of mobile technologies [7]. It was also further highlighted [48] that the quality and frequency of interactions of students with mobile apps are the most critical predictors of their academic performance, despite the initial levels of access. These results indicate that mobile learning use is a very important mediator between access and education.

H8: Mobile learning engagement mediates the relationship between access to mobile technology and students' academic development.

2.6 Theoretical framework supporting the research

The theoretical perspectives over which the relationships in this study will be explained are mostly based on the TAM, as well as the contributions of Constructivist Learning Theory and the Engagement Theory. According to [49], TAM presupposes that there are two beliefs that clarify the intention of a person to use a technology that ultimately determines the actual use and the outcomes of it. This framework has been widely employed in education technology research in explaining the behavioral intention and learning outcomes among students in reaction to computer-mediated objects, including mobile learning applications [50]. The TAM is also used in the present study to provide a premise to assume that in case students find the learning apps very easy to use and useful, they will probably use them, which will contribute to the academic progress. Also, the study is informed by Constructivist Learning Theory, which centers on the active involvement of the learners and the creation of knowledge through interactions with learning environments [51]. As long as teachers support mobile learning applications and students have access to them, they allow self-directed and collaborative learning, therefore supporting the ideas

of constructivism. Environmental enablers that facilitate this constructivist learning process are teacher support and access to mobile technology. The Engagement Theory [52] strengthens the model further by asserting that significant learning is achieved through engagement, especially when learners participate in interactive and meaningful activities. This research builds on existing frameworks for technology acceptance and mobile learning by incorporating behavioral engagement and contextual enablers into one model, namely instructor support and access to technology (see Figure 1). While TAM has traditionally focused on cognitive perceptions (ease of use and usefulness), it does not fully explain the behavioral mechanisms by which perceptions are translated into academic development. By proposing mobile learning engagement as a theoretically based mediator and embedding the contextual variables from constructivist and ecological learning perspectives, the study contributes to current knowledge and can provide a more holistic understanding of the working of mobile learning ecosystems in higher education settings.

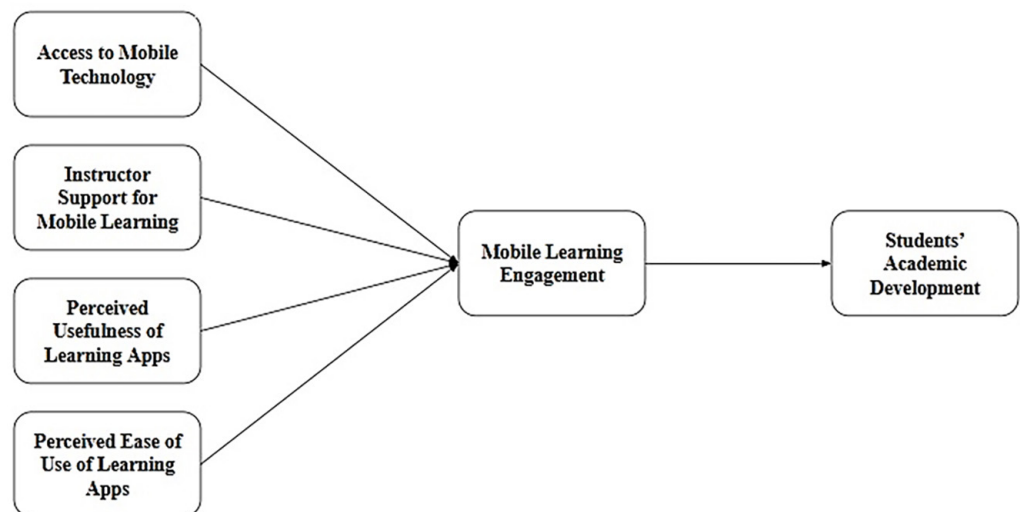


Fig. 1. Conceptual framework

3 METHODOLOGY

This study was conducted in a quantitative, cross-sectional survey design and was aimed at investigating the relationships between perceived ease of use, perceived usefulness, instructor support for mobile learning, access to mobile technology, mobile learning engagement, and academic development among undergraduate students in Chinese higher education. A survey approach was chosen due to the possibility of collecting standardized data from a relatively large student population engaged in mobile learning practices and is suitable for variance-oriented analytical techniques (partial least squares structural equation modelling—PLS-SEM).

3.1 Sampling and participants

The target population was undergraduate students in various universities in China if they frequently use mobile applications for academic purposes. A total of 234

valid responses were obtained by the convenience sampling technique. Although not very generalizable, convenience sampling can be widely applied in exploratory PLS-SEM studies because of its practicality and access to active users of technology. In order to have sufficient statistical power, sample size was assessed based on the “10-times rule,” which states that the minimum sample should be 10 times the number of structural paths directed to the most complex endogenous construct. The construct “Academic Development” is assigned four structural paths, which require at least 40 cases. The sample size of 234 therefore surpasses this threshold and is suitable for the estimation of the models.

3.2 Instrument development

The questionnaire was divided into two sections: demographic and measurement items for the latent constructs. All constructs were measured through the use of established and validated scales adapted from previous studies. Items on perceived ease of use and perceived usefulness were adapted from Davis [49] and are widely used in studies of TAM. Instructor support and access to mobile technology scales were drawn from current mobile learning and educational technology literature. Because access to mobile technology can be seen as a broad enabling construct, the items included in the study intentionally span both physical access (e.g., availability of devices, stability of connectivity) and digital access (e.g., institutional access to platforms, availability of learning content). This approach is in agreement with research that recommends access be conceptualized as a multifaceted condition rather than a single technical indicator. Mobile learning engagement was assessed in terms of behavioral, emotional, and cognitive engagement indicators adapted from Fredricks et al. [53]. It is important to note that engagement was measured only based on perceptions. While self-reports are typical in mobile learning research, they represent perceptual rather than objective engagement behaviors. This is admitted to be a methodological limitation. All items used a five-point Likert scale varying from 1 (“strongly disagree”) to 5 (“strongly agree”). The instrument was originally prepared in English and was translated into easy Chinese, and vice versa, to check for conceptual equivalence. A pilot test with 20 students proved clarity and reliability.

3.3 Data collection procedures

General mobile learning applications within the context of Chinese higher education would encompass institutional learning management application e.g. Chaoxing (Superstar Learning) and MOOC-based applications, discipline-specific education applications (e.g., language learning and test preparation applications), and communication and collaboration applications like WeChat that are often part of both formal and informal learning. The experience of students in Chinese higher education is characterized by a heterogeneous mobile learning environment, consisting of institutional learning management systems, discipline-specific educational applications, and communication tools, which are incorporated into the teaching and learning practices. Since students are usually able to move freely through these platforms in one course or learning task, confining the study to a particular application would have restricted the ecological validity of the engagement construct

and reduced inference scope. Despite the lack of constraint on the use of a single platform, the items of the survey were tailored to reflect the overall interest of students in the use of mobile applications to achieve academic goals, where the Internet provided students with access to learning materials and interactive learning facilities and discussion with their teachers and lecturers. Data were gathered through an online survey that was distributed through university mailing lists, online learning communities, and popular Chinese platforms such as WeChat. Participation was voluntary and anonymous. The survey was open for four weeks so that there was time for students with various majors and universities to participate.

3.4 Ethical considerations

The study followed institutional and international ethics standards. Ethical approval was obtained from the Institutional Research Ethics Committee of the Beijing Normal University (Approval No. BNU-EDU-2024-117). Participants were provided with an informed consent statement that included information on the voluntary nature of participation, confidentiality of data, and the absence of personal identifiers. They were told of their right to withdraw at any time without penalty.

3.5 Data analysis

Data were analyzed with the software SmartPLS 4. The PLS-SEM procedure was based on a two-stage procedure. First, the measurement model was evaluated using indicator reliability, internal consistency reliability (Cronbach's alpha and composite reliability), convergent validity (average variance extracted), and discriminant validity (HTMT and Fornell-Larcker criteria). Following satisfactory results when measuring the measurement model, the structural model was evaluated. Path coefficients, t-values, and p-values were produced by a bootstrapping procedure with a subsample generation of the data (5000 subsamples). Mediation analysis was performed to investigate the indirect influence of perceived ease of use, perceived usefulness, instructor support, and access to mobile technology on academic development through mobile learning engagement. While statistical mediation assesses the importance of indirect effects in a numerical way, the study also used some theoretical justification. Drawing from Engagement Theory and Constructivist Learning Theory, engagement is conceptualized as the behavioral mechanism between perceptions and contextual supports and academic outcomes. As such, mediation is understood as a statistical effect as well as a theoretically based, explanatory process. Explanatory and predictive relevance (variance accounted for (VAF), R², Q², and model fit indices (SRMR, d_{ULS})) were also examined.

4 RESULTS

Table 1 and Figure 2 show the reliability and validity measures for all the constructs employed within the study to ensure the soundness of the measurement model. Factor loadings (original sample estimate) for all the indicators are above the recommended 0.60, which ensures acceptable item reliability. All the items possess

extremely significant t-values and p-values ($p < 0.001$), which reflect strong indicator reliability. Cronbach's Alpha coefficients for all variables are greater than 0.70, from 0.745 to 0.903, indicating good internal construct consistency. Composite reliabilities (CR) for all constructs are also significantly higher than 0.70, from 0.855 for perceived usefulness to 0.934 for perceived ease of use, supporting high construct reliability. In addition, the AVE values for all constructs surpass the suggested 0.50 cutoff value for convergent validity, confirming convergent validity. Overall, these findings suggest that scale items consistently and effectively measure their associated constructs and are amenable to structural equation modeling with SmartPLS.

Table 1. Variables' reliability and validity

Variables	Indicator	Original Sample	T Values	P Values	Cronbach's Alpha	CR	AVE
Academic Development	AD1	0.783	21.110	0.000	0.867	0.909	0.715
	AD2	0.842	29.442	0.000			
	AD3	0.906	56.711	0.000			
	AD4	0.848	32.668	0.000			
Access to Mobile Technology	AMT1	0.775	31.474	0.000	0.888	0.913	0.601
	AMT2	0.736	13.663	0.000			
	AMT3	0.811	32.629	0.000			
	AMT4	0.821	27.599	0.000			
	AMT5	0.626	9.401	0.000			
	AMT6	0.825	34.173	0.000			
	AMT7	0.812	23.526	0.000			
Instructor Support for Mobile Learning	ISML1	0.860	34.650	0.000	0.903	0.926	0.675
	ISML2	0.808	25.179	0.000			
	ISML3	0.857	38.971	0.000			
	ISML4	0.832	28.906	0.000			
	ISML5	0.828	25.976	0.000			
	ISML6	0.739	13.618	0.000			
Mobile Learning Engagement	MLE1	0.777	17.322	0.000	0.875	0.909	0.667
	MLE2	0.839	35.299	0.000			
	MLE3	0.845	32.580	0.000			
	MLE4	0.842	38.742	0.000			
	MLE5	0.779	16.557	0.000			
Perceived Ease of Use	PEOU1	0.928	58.939	0.000	0.895	0.934	0.826
	PEOU2	0.909	52.808	0.000			
	PEOU3	0.889	39.536	0.000			
Perceived Usefulness	PU1	0.809	23.711	0.000	0.745	0.855	0.662
	PU2	0.861	53.162	0.000			
	PU3	0.769	18.190	0.000			

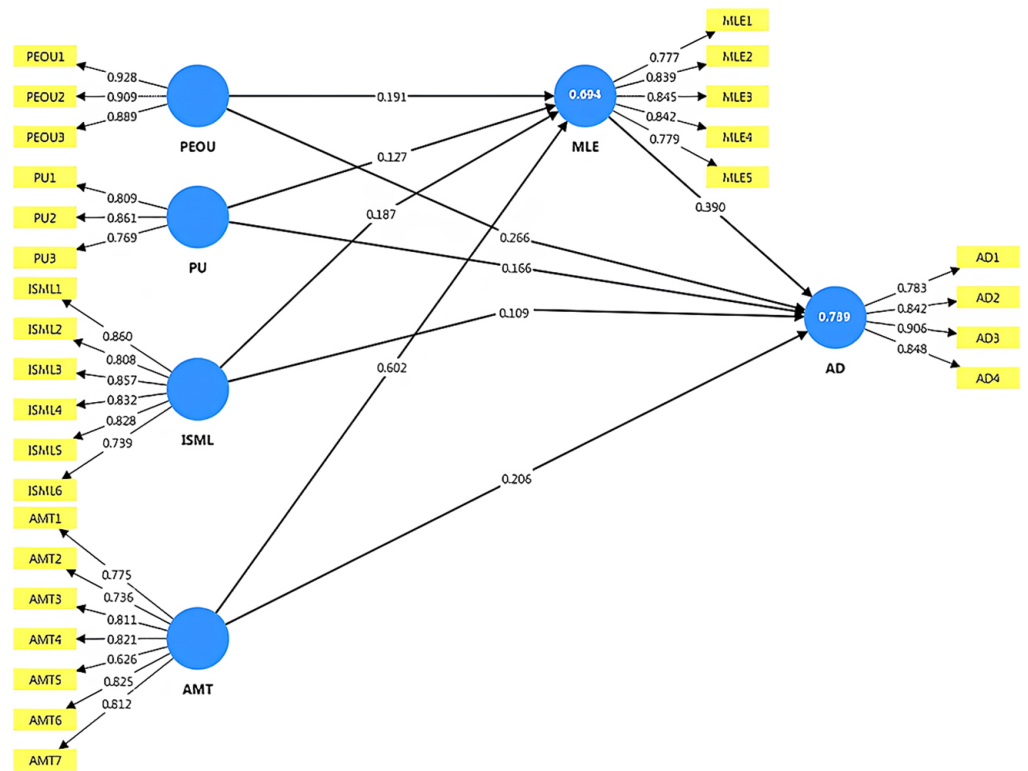


Fig. 2. Estimated model

Table 2 tests discriminant validity using the HMTM ratio and the Fornell-Larcker test. All the values in the HMT matrix fall below the 0.90 marker, which means that discriminant validity between the constructs is acceptable. Indicatively, the HMT of the mobile learning engagement and development of academic status is 0.868 with a high level of relationship, though the construct uniqueness is maintained. The Fornell-Larcker criterion restates discriminant validity by demonstrating that the square root of AVE (diagonal values) of each of the constructs is better than the correlations with other constructs. E.g., AVE has the square root of 0.909, which is greater than its correlation with other variables, such as access to mobile technology (0.534) and instructor support of mobile learning (0.540). This table provides confidence that all latent variables are empirically distinct from one another; that is, it confirms the design of the measurement model.

Table 2. Discriminant validity

	HMT					
	AD	AMT	ISML	MLE	PEOU	PU
Academic Development						
Access to Mobile Technology	0.795					
Instructor Support for Mobile Learning	0.737	0.824				
Mobile Learning Engagement	0.868	0.834	0.865			
Perceived Ease of Use	0.776	0.588	0.599	0.648		
Perceived Usefulness	0.820	0.699	0.757	0.703	0.836	

(Continued)

Table 2. Discriminant validity (Continued)

	HTMT					
	AD	AMT	ISML	MLE	PEOU	PU
Fornell-Larcker criterion						
Academic Development	0.846					
Access to Mobile Technology	0.711	0.875				
Instructor Support for Mobile Learning	0.650	0.838	0.842			
Mobile Learning Engagement	0.759	0.839	0.771	0.847		
Perceived Ease of Use	0.697	0.534	0.540	0.582	0.909	
Perceived Usefulness	0.671	0.567	0.615	0.568	0.788	0.814

The explanatory power and effect size of the structural model are provided in Table 3. The R-Sq of the academic development is 0.739, which implies that about 74% of the academic development variance in students is attributed to the independent variables. Similarly, mobile learning engagement has a high percentage of explained variance, with an R-Sq of 0.694. These denote that the model is very predictive. The f-square results reveal that the engagement of mobile learning (0.130) and the availability of mobile technology (0.401) have medium effects on academic development. Such variables as perceived ease of use and perceived usefulness possess less significant effect sizes but still contribute to the model. The model fit indices also confirm the suitability of the model. The SRMR of the saturated model and the estimated model is 0.078, which is lower than the acceptable value of 0.08, which indicates a good fit. The structure fit of the model is also justified by the d ULS.

Table 3. R-square, f-square, and model fit statistics

	F Square		R Square	
	AD	MLE	R-Square	R-Square Adjusted
Students' Academic Development			0.739	0.736
Access to Mobile Technology	0.028	0.401		
Instructor Support for Mobile Learning	0.004	0.036		
Mobile Learning Engagement	0.130		0.694	0.690
Perceived Ease of Use of Learning Apps	0.081	0.051		
Perceived Usefulness of Learning Apps	0.030	0.002		
	MODEL FIT			
	Saturated Model		Estimated Model	
SRMR	0.078		0.078	
d_ULS	2.461		2.461	

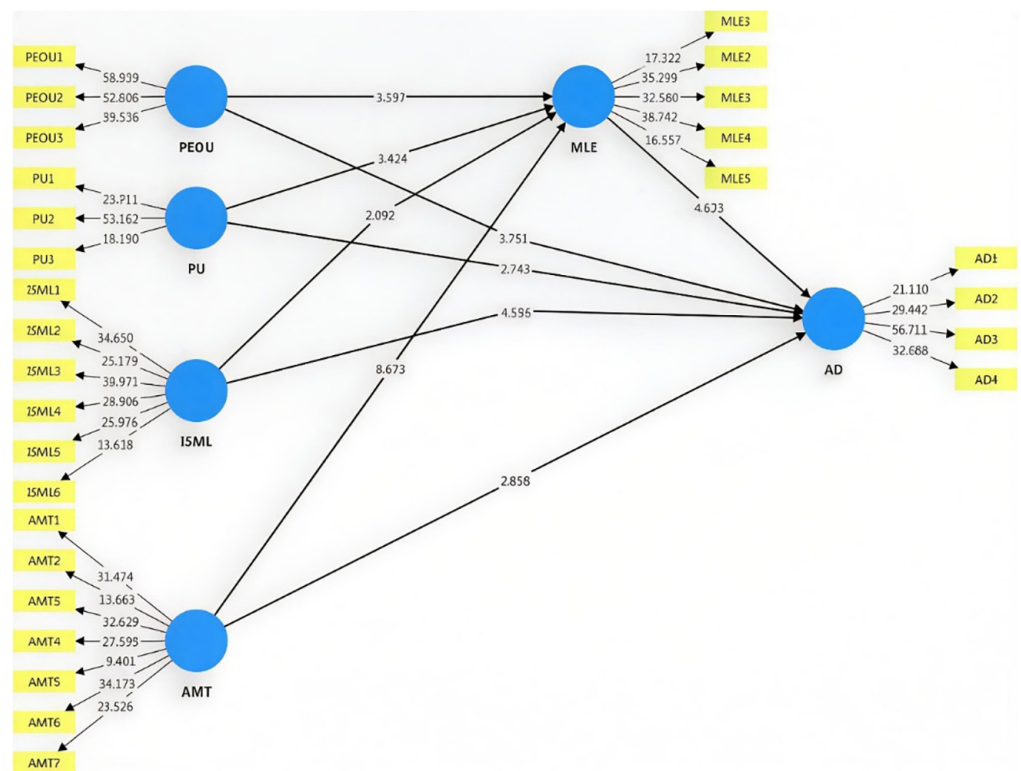


Fig. 3. Structural model for path analysis

Table 4 and Figure 3 indicate the results of path analysis, during which the direct and indirect relationship between the research variables is explored. The perceived ease of use has a significant direct correlation with academic development of 0.266 with a t-statistic of 3.751 and a p-value of 0.000. This implies that when the students find mobile learning apps to be user-friendly, it goes a long way into their academic growth. Similarly, there is a statistically significant and positive effect of perceived usefulness on academic development with a path coefficient of 0.166, a t-value of 2.743, and a p-value of 0.003. This implies that learners who consider mobile learning applications useful will be in a position to realize improvements in their academic results. The support of mobile learning by the instructor also shows a very high positive result of a 0.109 path coefficient, a t-value of 4.596, and a p-value of 0.000, which further reiterates the importance of the educator intervention in facilitating the academic growth of students. In addition, the mobile technology access has also shown a substantial influence on the academic development with a path coefficient of 0.206, a t-value of 2.858, and a p-value of 0.002. This finding indicates that the students who have a high level of access to mobile learning tools can probably perform well academically. Some of the key indirect impacts through mobile learning interaction are discovered in the analysis. The indirect relationship between the perceived ease of use and the academic development through mobile learning engagement is also significant with a path coefficient of 0.074, a t-value of 2.775, and a p-value of 0.003. This demonstrates that ease of use directly impacts academic performance and has an indirect impact on academic progress via engagement. Similarly, the indirect relationship of perceived usefulness on academic development through engagement has a significant path coefficient of 0.062 with a t-value of 2.480 and a p-value of 0.007, which means that perceived

usefulness influences engagement and the opposite is also true. Moreover, mobile learning instructional support also has a strong indirect influence on academic development with a path coefficient of 0.073, a t-value of 1.798, and a p-value of 0.036. This highlights that instructional support triggers increased involvement in mobile learning that subsequently brings changes to academic development. The relevance of both the technological and pedagogical variables is justified by all the proposed relationships, which support the mediating effect of the mobile learning engagement on the academic performance of students.

Table 4. Path analysis

Hypotheses	Original Sample	Standard Deviation	T Statistics	P Values
PEOU → AD	0.266	0.071	3.751	0.000
PU → AD	0.166	0.061	2.743	0.003
ISML → AD	0.109	0.024	4.596	0.000
AMT → AD	0.206	0.072	2.858	0.002
PEOU → MLE → AD	0.074	0.027	2.775	0.003
PU → MLE → AD	0.062	0.025	2.480	0.007
ISML → MLE → AD	0.073	0.041	1.798	0.036

5 DISCUSSION

With the advent of mobile knowledge learning technologies, the higher education landscape was restructured and offered fresh avenues of academic engagement, personalized learning, and knowledge construction. Because of the increasing significance of digital literacy in Chinese higher education and the high rate of mobile device penetration, it is necessary to better understand how students interact with learning applications. The current study was intended to investigate the interconnection between the main constructs, such as the perceived ease of use, perceived usefulness, instructor support, access to mobile technology, and engagement in mobile learning, to influence the academic development of students. According to the TAM, Constructivist Learning Theory, and Engagement Theory, empirical evidence presented in this study can provide insights into the way in which the introduction of the use of digital tools in colleges contributes to the achievement of learning outcomes. The support for all hypothesized relationships highlights the dual role of technical and human aspects in promoting efficacious mobile learning experiences, underlining the central function of engagement as an intermediary mechanism.

The findings provide some actionable insights for international institutions of higher education. In systems with strong learner autonomy (e.g., Scandinavia, Canada), perceived usefulness may be the dominating driver of engagement. On the other hand, in teacher-centered cultures (e.g., East Asia, Middle East), instructor support may have a greater role in shaping learner behavior. Universities can thus make the model their own by emphasizing the contextual factor that is most compatible with their pedagogical norms and ensuring that engagement mechanisms stay front and center of mobile learning strategy.

The outcomes of this study offer strong evidence for Hypothesis 1, verifying that the ease of use perceived for learning apps has a substantial positive impact on

students' academic progress. This is very much in line with the TAM, which holds that ease of use is a core driver of users' acceptance of technology in educational settings [49]. Suppose college students in China perceive learning applications as being intuitive and easy to use. In that case, they are likely to incorporate them into their daily academic tasks, which enhances their understanding, retention, and performance. Simple user interface, convenient access to academic materials, and little cognitive burden of using the functionality of applications will lead to increased utilization, which in turn will improve academic participation and advancement [54]. The obtained result can also be connected to the current literature in Chinese education settings, which emphasizes the role of student-centered environments in boosting the use of technology and the achievement of better learning outcomes. Moreover, based on the Constructivist Learning Theory, convenience improves active learning as it helps students to focus on knowledge creation and does not mess with technical problems.

Hypothesis 2 was also empirically validated, according to which the perceived usefulness of learning apps is a strong predictor of the academic developments of Chinese college students. TAM claims that the perceived usefulness directly influences user acceptance and the actual usage behavior [26]. When the students understand that a learning app will help them finish tasks more efficiently, they will better learn the course materials or even achieve higher academic results; therefore, there is a better status that they will use the technology. This observation is especially true in the case of the fast-growing education sector in China. The sufficiently high level of intelligent functionality in the majority of learning apps, such as customized quizzes, automated feedback, and real-time performance monitoring, produces the impression of academic progress, which results in the recurrence of use and more frequent interaction [6]. This connection is also promoted by Engagement Theory, as it observes that deep learning occurs when students are engaged in goal-focused activities using technology. Thus, not only does the utility of apps address an academic utilitarian need, but it also promotes higher-order cognition and self-directed learning.

The facts that support Hypothesis 3 show that the academic development of students positively depends on the support of mobile learning by their teachers. This fact highlights the importance of teachers in shaping the attitudes of students towards educational technology. Instructor support includes such activities as the recommendation of specific apps, technical support, the integration of app-related tasks into the classroom instruction, and the promotion of their frequent usage [1]. Such measures will make learners feel confident about using learning apps, which will boost their academic activities and performance. This is against Constructivist Learning Theory, which postulates that learning is a social process whereby teaching by an experienced teacher supplements cognitive construction. Also, the facilitator aspect of the instructor is complemented by the emphasis of Engagement Theory on real-world and participatory learning activities [53]. Teacher dominance practices in Chinese classrooms, where historically teacher dominance has been emphasized, may be highly influenced by instructor support of mobile learning technologies, and this will increase the effects of technology-enhanced learning.

The results are also favorable to Hypothesis 4, according to which the academic development of students is strongly affected by the access to mobile technology. Stable access to smartphones, tablets, and internet connectivity is one of the basic facilitators of mobile learning in the Chinese learning environment, where mobile phones are being used daily by young people [14]. Students who have consistent

access to mobile phones will have a greater chance of using learning applications to learn, consolidate knowledge, collaborate with others, and manage academic assignments. This is in line with studies that have established the relevance of digital access and access to infrastructure in the success of mobile learning [19]. The access allows the students to customize their learning conditions, and students are now able to study at any time and location, thus extending the learning past the classroom boundaries. Engagement Theory supports this finding by saying that the technological situation must be attainable and consistent to ensure that learners can successfully use the online materials and socialize with their classmates. In this way, the institutional and governmental measures aimed at reducing the digital divide as well as enhancing access to mobile learning facilities in China are fundamental in ensuring that technology-enhanced education maximum benefits are realized.

The fact that Hypothesis 5 gets accepted means that learning apps can be perceived as easy to use by students, and such a perception encourages them to engage in the mobile learning process to an even greater degree, which in its turn leads to improved academic development. Similarly, the adoption of Hypothesis 6 would suggest that the perceived usefulness of learning apps would lead to increased learning engagement that further leads to better academics. Such mediated relationships have strong foundations on TAM, in which perceived ease of use and perceived usefulness are observed to be important antecedents of behavioral intention to use technology, which leads to the eventual patterns and consequences of the use [49]. The intervention of mobile learning interaction introduces a deeper set of how these perceptions are being carried into academic performance. Constructivist Learning Theory provides the description of the process by the following statement: valuable learning happens when students are engaged with the material in a manner of autonomous interaction. Reflective, self-paced, and individualized learning can be achieved with the help of learning applications that are practical and easy to navigate. The explanation is complemented by the Engagement Theory [52], which states that authentic learning occurs when learners are engaged both mentally and behaviorally in interactive processes. Therefore, mobile engagement is the interface between the positive attitude towards technology and the actual academic performance of the students, which gives a theoretical and empirical basis to the development of the student-centered digital learning spaces.

The Hypothesis 7 that was accepted presupposes that teacher support appropriate to mobile learning, including the use of apps in classes, educating students on app usage, and encouraging them to learn more about educational technologies, yields a better apprehension of students' engagement. It, hence, results in high academic performances. On the same note, Hypothesis 8 evidence also states that access to mobile technology is not sufficient, but rather, it is the interaction with that technology that facilitates access to translate into valid learning outcomes [55, 56]. These findings support the fundamental principles of Constructivist Learning Theory that postulate facilitation of scaffolding by the teacher and the active role that the learner plays towards developing knowledge based on the interactions between the learner and the environment. This is supported by Engagement Theory, which opines that the access of the interactive and collaborative digital resources should be complemented with valuable engagement to result in academic achievement [57, 58]. Mobile learning engagement as a psychological and behavioral process through mediating the relationship between contextual support (instructor support and access) and academic growth represents a core psychological and behavioral process where the enabling conditions are transformed into measurable academic outcomes [38]. These discoveries point to the necessity of providing Chinese academic institutions

with not only access and teacher training but also the development of learning strategies that can ensure long-term involvement of the students in using the mobile learning means.

In general, the findings of the current research are a detailed description of the effect of mobile learning applications on academic success through an intricate set of perceptions, resources, and student habits. All the hypotheses under support show that involvement of students is a significant middle factor between the acceptance of technology and academic performance, and that the adoption of mobile tools is not sufficient without active and meaningful use. The integration of TAM and constructivist and engagement models has remained one of the robust theoretical perspectives in which to understand the Chinese academic mobile learning dynamics. The results are both theoretical and practical for the educationists, app developers, and policymakers in the quest to enhance student achievement in digital innovation. Lastly, the study justifies that when the students are assisted, feel they are getting something of worth, and are inspired to get deeply involved with technology, their schooling career might significantly increase.

6 CONCLUSION

Overall, the study offers information on the ideal significance of mobile learning applications in the establishment of the learning outcomes among Chinese college students. By reviewing the impact of perceived ease of use, perceived usefulness, pedagogic support, and availability of mobile technology on learning and the mediating role of mobile learning engagement, the work gives a comprehensive vision of how digital resources can influence learning outcomes. The ease of all the hypotheses confirms the superiority of user perception, environmental support, and digital accessibility in improving student performance through mobile platforms. Following the TAM with the contribution of the Constructivist Learning Theory and the Engagement Theory, the findings indicate not only the technological but also the pedagogical and engagement-based elements of digital learning. The study confirms that the promotion of active involvement with the help of mobile devices can bridge the divide between the use of technologies and significant academic success. Overall, the study has both theoretical and practical implications, as it introduces a sophisticated framework that can be used by educators, developers, and policymakers to develop more efficient mobile learning platforms that can support the evolving demands of modern students in institutions of higher learning.

7 IMPLICATIONS

7.1 Practical implications

Although the findings are considered within the Chinese higher education framework, they can be transferred to the learning abroad mobile learning programs. The identified core mechanisms, the perception of technology by students, and the support of the instructors with the context, the access to the mobile devices, and the participation are regarded as typical factors of the digital learning frameworks worldwide. Nonetheless, their impact may vary in relation to the cultural norms, institutional roles, and levels of digital infrastructure maturity. Perceived usefulness should mediate engagement in situations where the degree of autonomy of the

learner is high and where learning is decentralized, whereas in situations where instructor power is important in the determination of learning behavior, pedagogical support can play a bigger mediating role. The applicability of the research thus is not limited to China, as long as its application considers contextual factors like the digital equity, pedagogical culture, and the institutional support systems. This cross-cultural awareness is contributing to the value of this study to the global discourse on mobile learning ecosystems.

The findings of this study offer meaningful practical implications to educators, institutional policymakers, and ed-tech developers wishing to enhance the academic growth of college students with the help of mobile learning. First of all, the fact that the perceived ease of use and perceived usefulness were on the forefront of academic development suggests that Chinese institutions should invest in a user-friendly and pedagogically significant mobile app that has been integrated near the academic goals of the students. Teachers must be motivated to actively use such applications in their teaching practice and provide continuous support, which will help students gain confidence and motivation. Moreover, by enabling more students to access mobile technology, either by institutionalizing it or by upgrading their learning infrastructure, they can significantly increase their learning. Training of the faculty and students on how to use educational apps productively could also enhance the learning process. The developers of the apps should also incorporate interactive, personalized, and engagement-based features in their strategy because student engagement has become one of the determinants of their academic output. Combining user-friendly design, content, and teaching aids, the stakeholders are able to create a mobile learning environment that is not merely technologically on the cutting edge but also effective in terms of academics.

7.2 Theoretical implications

Theoretically, this study makes an addition to the body of knowledge on technology acceptance and academic development because it develops the TAM by additions of constructs of Constructivist Learning Theory and Engagement Theory. By the depiction of the mediating role of mobile learning engagement, the study supplements the classical aspect of TAM in its focus on behavioral intention and system use by a pedagogically meaningful outcome: academic development. This extension offers a more holistic approach to assessing technology in educational settings, especially in the fast-changing world of mobile learning. In addition, by confirming the role of external variables such as teacher support and facility access to mobile technology, the study highlights contextual and environmental enablers that are frequently underemphasized in technology adoption frameworks. The convergence of constructivist and engagement theories also emphasizes learners' active construction of knowledge and improvement of academic outcomes through interactive digital encounters. This study, therefore, provides the framework for future theoretical frameworks that are technology-based but pedagogically enriched, particularly in Asian higher education contexts. This study is an improvement of the classical TAM, as it entails contextual and pedagogical aspects that enhance its theoretical context. Traditional TAM applications mainly focus on the perceptions of ease of use and usefulness of the users as the factors influencing behavioral intention and use of the system. Nonetheless, the study adds more elements to the model by incorporating instructor support and access to mobile technology as important contextual variables based on the socio-pedagogical environment where learning technologies are implemented.

Moreover, the incorporation of mobile learning engagement as a mediating variable takes TAM to a new stage of being a predictive model of technology acceptance to an explanatory model of academic growth. This theoretical extension recognizes that the process of technology acceptance in education is not an entirely cognitive process but rather is influenced by instructional context, accessibility, and long-term behavioral engagement. Therefore, the study has a role to play in the development of debates about the flexibility of TAM to education systems and its applicability in examining digital learning practices in different learning institutions.

7.3 Limitations and future directions

The current study has several limitations. The use of convenience sampling limits the generalizability of the results to larger populations of students. Although the study results are robust and internally consistent, it has to be admitted that there are several limitations. The convenience sampling and sample size of 234 undergraduate students, despite being adequate to estimate PLS-SEM and adhering to the ten times rule, limit the generalizability of the findings. The system of higher education in China is very heterogeneous with respect to institutional levels, its characteristics in the development of different regions, and digital infrastructure, and the sample under consideration might be restricted to represent this variety in all its aspects. The results can therefore be taken as a guide and not a reflection of all the Chinese universities. All constructs were assessed based on the self-reported perceptions, which include mobile learning engagement, which may not necessarily reflect actual behavioral patterns and actual test scores due to social desirability or recall biases. The lack of objective behavioral data (such as app usage logs) is a limitation with the engagement construct, as it compromises the precision of engagement. The cross-sectional design rules out any causal inferences, while contextual variables such as digital literacy, socioeconomic background, and discipline-specific learning environments were not controlled. Future research should include mixed-method methodologies, behavioral analytics, and sampling strategies that are more diverse in order to increase explanatory depth and external validity. In future studies, more extensive and multi-site big sampling techniques, such as stratified or probability sampling techniques, must be used to provide better external validity and provide stronger conclusions about populations. Longitudinal and mixed-method designs might help supplement the validity of the proposed model in the context of various institutional and regional environments.

Future research can further the research done in this work by looking at the longitudinal designs in order to gain more knowledge into the causal relationships and the long-term effects of mobile learning in academic development. The sample of students representing different regions, institutions, and students of different levels should contribute to the external validity of the results. The inclusion of moderating or control variables such as gender, discipline in school, or technology experience was also a possibility that researchers could use to unlock further insights. In addition to quantitative surveys, the qualitative data collection tools, i.e., interviews or focus groups, may also be used to learn more about the mobile learning engagement. Further studies on the effectiveness of the diverse mobile learning applications, such as gamified applications, collaborative applications, and discipline-specific applications, can be conducted to establish the most effective application that can lead to better learning outcomes in different learning environments.

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