Examining the mediating role of digital competence and the moderating role of technostress in the effects of facilitating conditions on higher education students' digital informal learning

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Although studies have highlighted the importance of facilitating conditions in enhancing students' digital informal learning (DIL), the effect mechanism is still unclear. This study examined the mediating role of digital competence and the moderating role of technostress between facilitating conditions and DIL. Data were collected from 385 undergraduates from two Chinese universities and analysed using AMOS and SPSS. The results indicated that (a) facilitating conditions predict students' digital competence and DIL positively; (b) digital competence has a positive mediating effect on the association between facilitating conditions and DIL; and (c) technostress plays as a negative moderator in the relationship between facilitating conditions and DIL. In conclusion, to enhance higher education students' DIL, educators and administrators should consider facilitating conditions, digital competence and technostress.

Implications for practice or policy:

- University administrators could facilitate students' DIL by providing adequate infrastructure and creating a positive atmosphere for DIL.
- Educators should recognise the importance of students' digital competence and create opportunities (e.g., providing sufficient elective courses and implementing reward strategies) for their development.
- Students could avoid experiencing too much technostress by making their DIL schedules appropriately and participating in physical activities.

Keywords: digital informal learning (DIL), facilitating conditions, digital competence, technostress, higher education students, structural equation model

Introduction

The prevalence of digital technologies is transforming how individuals communicate, work and learn. In today's information age, learning with digital technologies inside and outside class is becoming an indispensable part of students' daily lives, providing students with opportunities to learn what they need regardless of time and constraints (He & Zhu, 2017). Digital informal learning (DIL) refers to the situation where learners use digital technology for learning in their free time, making it easier for them to access, manipulate, recreate and spread informative knowledge (He et al., 2018).

The crucial factors influencing students' usage of technologies for learning purposes in higher education are issues that have attracted the increasing attention of scholars (Lai et al., 2012; Qi, 2019). These either focused on a specific tool for learning or general technology-enhanced learning. Typical variables impacting students' behaviour intention to learn with technology are attitude (Verkijika, 2019), usability (Jones & Healing, 2010), instructional support (Gabriel et al., 2012) and technostress (Qi, 2019). Specifically, students' positive attitude towards a given technology can increase their intention to adopt

it (Delcker et al., 2024; Labrague et al., 2023; K. Li, 2023; Verkijika, 2019). Usability concerns the knowledge and guidance enhancing technology acceptance, which significantly and positively predicts students' behaviour intention to learn with technology and engagement in information and communications technology (ICT)-supported learning (Dahleez et al., 2021; Joo et al., 2014). Instructional support concerns students' perception of school support, which may consist of multiple dimensions, such as service, technical and social support (Kakada et al., 2019). Several scholars across diverse educational technology have emphasised the critical role of instructional support in ICT-supported learning use contexts, such as learning management systems and artificial intelligence (AI)-powered tutoring tools (Al-Nuaimi & Al-Emran, 2021; Ni & Cheung, 2022). Technostress concerns the stress resulting from technology use, which is usually considered an obstacle for students to learn with technology (Upadhyaya & Acharya, 2020; X. Wang et al., 2020).

As a learning method with high flexibility, DIL in higher education has recently attracted increasing concern among scholars (He et al., 2018; He & Zhu, 2017; Lai et al., 2012). Studies have tended to explore the effectiveness of digital tools (e.g., social media) to support DIL using qualitative research methods (e.g., B. Lee & Sing, 2013) or focus on the predicting factors of DIL from the perspective of students' characteristics (e.g., digital competence and attitude towards DIL) (He et al., 2018; He & Zhu, 2017). However, investigating the effect of environmental factors is scarce and how environmental and personal factors work together on students' DIL remains unclear.

To better understand what improves students' DIL, it is essential to consider the role of the facilitating conditions provided by universities or colleges because sufficient facilitating conditions are an essential prerequisite for students' adoption of technology for learning (Abbad et al., 2009; El-Gayar & Moran, 2006). For instance, He et al. (2018) found that facilitating conditions provided by universities positively predict students' perceived behavioural control, which in turn leads to increased actual engagement in DIL. Benson and Mekolichick (2007) confirmed that adequate facilitating conditions, including learning resources and the availability of hardware and software, create the potential for students to use technologies for learning. Lai et al. (2012) also found that facilitating conditions (e.g., encouragement and support provided by peers and teachers) can enhance the usage of technologies for learning among Hong Kong students. Studies have accumulated much evidence to support the importance of facilitating conditions. Thus, it is not surprising that several scholars identified facilitating conditions as one of the crucial variables in enhancing students' learning with digital technologies (e.g., He et al., 2018). However, some scholars reported that the influence of facilitating conditions on technology use for learning is weak or even insignificant. For instance, Teo (2011) reported that sufficient learning conditions do not significantly affect individuals' e-learning adoption. Morrison and Camargo-Borges (2016) also argued that adequate facilitating conditions may bring innumerable opportunities for students' DIL. However, learning transformation to DIL will not happen if technologies are added to the educational system. These findings suggested that some boundary variables may influence the association between facilitating conditions and DIL. Thus, the present study posited two possible variables (i.e., digital competence and technostress) to better understand the mechanism between facilitating conditions and DIL.

Digital competence is an important capability for lifelong learning in our information age and is considered essential to DIL (He & Zhu, 2017). We expected that digital competence may mediate the relationship between facilitating conditions and DIL. Additionally, technostress describes users' stress resulting from their disability to cope with the technology demands (Tarafdar et al., 2011), which is closely linked with technology use. Although the new generation of college students is usually considered "digital natives" (Prensky, 2001), they are still at a high risk of experiencing technostress when using technologies (Boonjing & Chanvarasuth, 2017; Yao & Wang, 2022). This study posited that technostress may negatively moderate the relationship between facilitating conditions and DIL. Thus, this study aimed to understand how facilitating conditions influence students' DIL by addressing the following three questions:

- Research question 1: How do facilitating conditions influence students' DIL?
- Research question 2: Does digital competence mediate the association between facilitating conditions and DIL?
- Research question 3: Does technostress moderate the association between facilitating conditions and DIL?

The rest of the paper is organised as follows: Firstly, we provide the theoretical background and the research hypotheses. Secondly, we introduce the research method, including instrument design, data collection and analyses. Subsequently, we present results, discussion, contributions, implications and limitations . Finally, we discuss our conclusions.

Literature review and hypotheses development

As mentioned above, it is necessary to consider environmental and individual characteristics and interactions to understand students' DIL. The role of facilitating conditions, digital competence and technostress in evaluating learners' adoption of technology for educational purposes has been a concern in previous literature; knowledge is scarce regarding their impact on DIL. Investigation of the influences of these factors is essential to understanding students' DIL.

DIL

The pervasiveness of the Internet and smart devices has led to unprecedented development in the quantity, quality and ease of access to knowledge, digitising a considerable part of informal learning (Galanis et al., 2016). DIL is a dynamic informal learning process supported by digital technologies, with which individuals can search, access, manipulate, disseminate and recreate informative content easily (He et al., 2021). We have come to a world where DIL is becoming indispensable for people of different ages and professions (Mehrvarz et al., 2021), especially for college students. Compared to formal learning, the advantage of DIL is obvious. Firstly, there are various DIL tools and resources available for learners to use free of charge or at a low price, such as social media (Degner et al., 2022; Madge et al., 2009), specially developed learning applications and platforms (Nie et al., 2020) and massive open online courses (Morrison & Camargo-Borges, 2016). Secondly, learners can control learning, selecting what to learn, when to learn, how to learn and even how to evaluate the learning autonomously during DIL (Holland, 2019; Meyers et al., 2013). Thirdly, students can benefit a lot from DIL, such as improved academic achievement (Mehrvarz et al., 2021), higher learning engagement (Pechenkina et al., 2017) and better knowledge acquisition (Sommerauer & Müller, 2014).

DIL consists three dimensions (He et al., 2021; Mehrvarz et al., 2021). The first dimension is cognitive learning (CL), which refers to individuals using digital tools for learning through physical or psychological means (Mayer, 1998). The second dimension is metacognitive learning (MCL), which focuses on planning and organising learning, monitoring comprehension and evaluating learning outcomes (Mayer, 1998; Mehrvarz et al., 2021). The last dimension is social and motivational learning (SML), which focuses on interactions with others in the digital setting to obtain support and motivation to learn (Mayer, 1998; Vermunt, 1996). A series of studies have reported that DIL can enhance students' academic performance, including increased English language proficiency (Lee & Dressman, 2018), learning engagement and motivation (Proulx et al., 2017) and self-reported academic performance (Mehrvarz et al., 2021).

Facilitating conditions, digital competence and DIL

Facilitating conditions

Facilitating conditions refer to individuals' perceived availability of support in their environments that can inspire and enhance their technology usage, which is crucial to technology adoption for learning purposes (Lai et al., 2012). Several studies have confirmed the critical role of facilitating conditions in enhancing students' adoption of e-learning systems (Abbad et al., 2009), mobile technologies (tablet computers) (El-Gayar & Moran, 2006), and Web 2.0 technology-supported learning (Ajjan & Hartshorne, 2008). For

instance, Lai et al. (2012) investigated 264 Hong Kong undergraduates to explore the factors influencing their technology usage for learning. They found that facilitating conditions positively affect students' computer self-efficacy and technology adoption.

Scholars have identified two primary sources of facilitation to improve individuals' adoption of technology for learning and teaching. The first is support provided by teachers and peers (Lai et al., 2012; Lai & Gu, 2011). Students are usually motivated by peers to engage in online learning and prefer using technologies their teachers recommended (Gray et al., 2010). The other is the availability of tools and resources (Mehlinger & Powers, 2002). Lack of sufficient infrastructure (e.g., computers) and inadequate technical service are common obstacles that prevent teachers from using technology (Mehlinger & Powers, 2002; Teo, 2011). Thus, it is unsurprising that facilitating conditions are considered an essential prerequisite for students' adoption of technology for academic purposes (e.g., He et al., 2018). However, other literature has reported that the effect of facilitating conditions on students' learning with technology is weak or even insignificant (e.g., Morrison & Camargo-Borges, 2016; Teo, 2011), suggesting the existence of boundary factors.

The present study defines facilitating conditions as students' perceived availability of support and resources in their colleges or universities that encourage and facilitate DIL. Without appropriate support and guidance, some students may know little about how to learn effectively with the help of digital technologies (Thomas et al., 2019). Studies have confirmed that encouragement and support provided by peers and teachers are dominant predictors of students' technology use for learning (Lai et al., 2012). Recent studies have also highlighted the importance of facilitating conditions in students' adoption of AI tools for educational purposes. For instance, Alshammari and Alshammari (2024) found that facilitating conditions significantly and positively impact students' intention to adopt ChatGPT. Al Shamsi et al. (2022) reported that facilitating conditions are critical predictors of students' use of AI-based voice assistants for educational purposes. In this regard, it is reasonable to expect students to likely engage in DIL as more facilitating conditions are provided. Thus, we formulated the following hypothesis:

- H1: Facilitating conditions will have a positive effect on students' DIL.

Digital competence

Digital competence refers to a set of abilities when using ICT, including technological skills, ethical knowledge and cognitive capabilities (Mehrvarz et al., 2021). Digital competence and digital literacy are often synonyms (Calvani et al., 2012), both of which are critical capabilities for lifelong learning (European Commission, 2006). Individuals with high levels of digital competence can employ digital tools to obtain digital resources flexibly, identify information critically and cooperate with colleagues using various digital tools and applications effectively.

Among the several theoretical frameworks of digital competence, the framework introduced by Calvani et al. (2012) is widely recognised and used. They argued that digital competence consists of three interconnected elements: technological skills, cognitive skills and ethical knowledge. Specifically, technological skills (TS) describe the ability to identify and tackle technological problems effectively, such as recognising technological troubles, charting out processes and selecting the most suitable technological solution. Cognitive skills (CS) describe the capabilities to search and identify information alongside the information's reliability and appropriateness. Thus, organising data, selecting and interpreting graphs,and evaluating information reliability are everyday activities that need cognitive skills. Ethical knowledge (EK) concerns the ability to interact with others constructively and responsibly using accessible technologies, such as safeguarding oneself, respecting the Net and understanding social and technological inequality. In this study, we adopted the digital competence framework proposed by Calvani et al.

Studies have highlighted the positive influence of digital competence on students' learning engagement and performance in DIL (Elstad & Christophersen, 2017; Mehrvarz et al., 2021; Nyikes, 2018). For instance, scholars have confirmed the critical role of digital competence in learners' performance in different educational contexts, including lower secondary students (Hatlevik et al., 2015), vocational high school

teachers (Mangiri et al., 2019) and university educators (Yazon et al., 2019). Additionally, He and Zhu (2017) empirically confirmed that students' digital competence is positively associated with their engagement in DIL. A recent study also reported that AI competence is an essential predictor of students' intention to adopt AI tools for educational purposes (Delcker et al., 2024).

Furthermore, students' digital competence is considered a school-based competence, which is strongly influenced by the school environment (Meyers et al., 2013). The accessibility and use frequency of technology significantly impact all subdimensions of digital competence (Diaz-Garcia et al., 2023). Pettersson (2018) also argued that digital competence should not be treated as an isolated phenomenon but as an organisational phenomenon influenced by contextual factors embedded within the organisation. Additionally, in an organisation that provides sufficient opportunities for collaborative learning of technology, such as relevant courses, associations and projects, students tend to be equipped with a higher level of digital competence (Cortés et al., 2017). Since colleges or universities are essential spaces where students' digital competence is employed and cultivated (Meyers et al., 2013), positive facilitating conditions, such as sufficient support provided by teachers and peers, easy access to infrastructures and resources may promote students' digital competence. Based on the literature mentioned above, we formulated the following hypotheses:

- H2: Facilitating conditions will positively affect students' digital competence.
- H3: Students' digital competence will positively affect their DIL.
- H4: Students' digital competence will mediate the effect of facilitating conditions on students' DIL.

Technostress and DIL

Technostress is broadly defined as the psychological strain triggered by using technologies (G. Zhao et al., 2021). It is considered a dark side of technology use, which may lead to adverse outcomes, such as decreased job satisfaction (Suh & Lee, 2017; Tarafdar et al., 2011), insufficient sleep (Q. Wang et al., 2023), low work performance (L. Li & Wang, 2021; Tarafdar et al., 2015; Upadhyaya & Acharya, 2020) and decreased intention to adopt technology (Jena, 2015). Several scholars have argued that, in addition to affecting technology adoption directly, technostress may have a negative moderating effect on the associations between predictors (e.g., perceived usefulness) and technology adoption intention (e.g., Verkijika, 2019; Q. Wang et al., 2022). Individuals with a high level of technostress may refuse to use a given technology, even if they recognise its usefulness. Although studies have confirmed the "negative" nature of technostress, recently, scholars have pointed out that technostress consists of both positive and negative sides (Shi et al., 2024; Tarafdar et al., 2019). Also, empirical studies have have found that some subdimensions of technostress, such as techno-overload and techno-uncertainty, can lead to greater productivity and innovation among individuals in organisations (Q. Wang et al., 2023; X. Zhao et al., 2020). Thus, it is necessary to critically view the nature of technostress according to the specific technology use situations (Tarafdar et al., 2019). In the context of DIL, students usually have ample freedom to choose their preferred learning methods without any restrictions. Students with higher levels of technostress may be less inclined to conduct DIL even in an environment with friendly facilitating conditions. This may explain why adding technologies to the educational system does not necessarily lead to students' transformation to DIL (Morrison & Camargo-Borges, 2016). In this regard, we proposed that technostress plays a possible moderator, which may provide a better explanation for the inconsistent findings about the influence of facilitating conditions on DIL. Thus, we formulated the following hypothesis:

- H5: Technostress will moderate the effect of facilitating conditions on students' DIL, such as the effect will decrease when technostress increases.

The present study

Most studies have confirmed the critical role of facilitating conditions in enhancing students' DIL, while others have argued that facilitating conditions are not as effective as expected. Thus, adding boundary

factors is necessary to further understand the impact mechanism of facilitating conditions on students' DIL. Guided by relevant literature, this study formulated a moderated mediation mode that posits digital competence as a mediator and technostress as a moderator. The theoretical research structural model is shown in Figure 1.

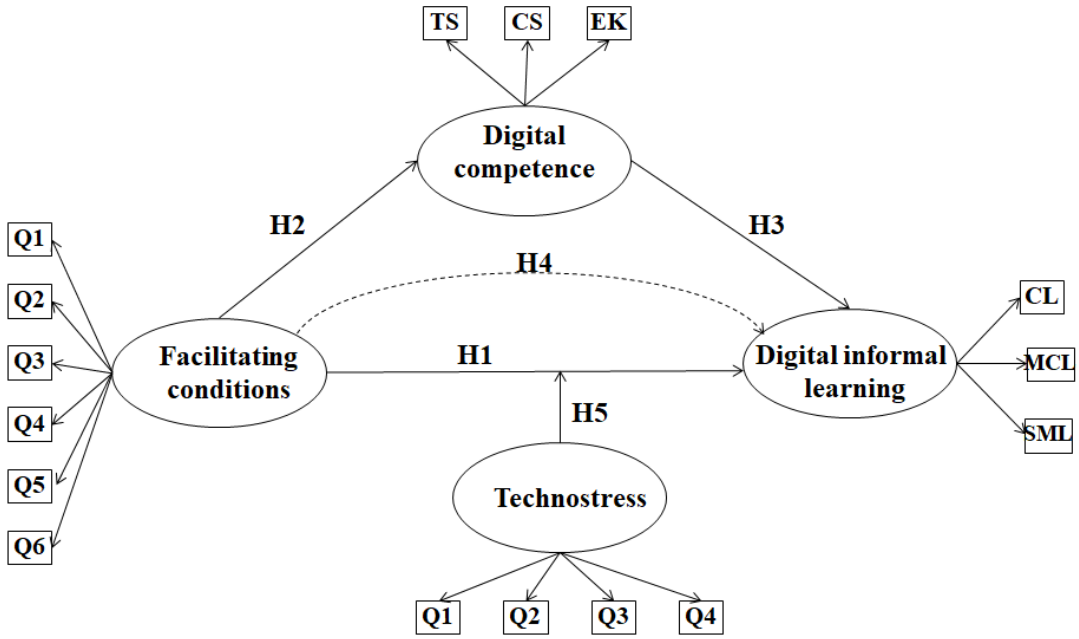

Figure 1. The conceptual model

Method

Participants

An online survey was employed to evaluate the proposed conceptual model and collect data from undergraduates from two public universities in southern China. A questionnaire on students' DIL was designed and sent to students via two commonly used social software applications (i.e., WeChat and QQ). Data collection was performed with the approval of the institutional ethics department. All participants engaged in the survey anonymously and voluntarily, and they could opt out at any time. Data collection lasted 10 days (2–12 April 2023). We received 415 responses; after deleting the responses which were answered with the same option for all items, 385 valid responses remained (Table 1). Thus, data analysis was conducted with a valid sample of 385 students.

Table 1
Demographic distribution of the valid respondents

Demographics	Items	Number	Percentage
Gender	Female	207	53.77%
	Male	178	46.23%
Grade	Freshman	114	29.61%
	Sophomore	101	26.23%
	Junior	89	23.12%
	Senior	81	21.04%
Duration of DIL per week	< 1 hour	41	10.65%
	1–3 hours	239	62.08%
	3–6 hours	58	15.06%
	> 6 hours	47	12.21%
Total		385	100%

Instrument development

DIL

The instrument used to examine students' DIL was revised from Mehrvarz et al. (2021). Since the original instruments are in English and our participants are Chinese, back-translation was used to ensure the validity and appropriateness of the survey questions. Specifically, 12 items were employed to measure the three dimensions of DIL, with four items per dimension. Example items are "I often use ICTs to learn knowledge related to my discipline at the time after class", "I often use ICTs to explore learning methods and strategies at the time after class", and "I often use ICTs to keep motivation in learning at the time after class". Confirmatory factor analysis was performed to examine the validity of the instrument. According to the criterion that the standardised factor loadings of items should not be less than 0.5 (Schumacker & Lomax, 2004), two items (i.e., CL4 and MCL4) were removed due to low factor loadings. Then, the standardised factor loadings of the remaining 10 items were above 0.5 (ranging from 0.776 to 0.920). The fit index of the instrument was acceptable, with $\chi2 = 79.559$, df = 32, p value = 0.000, $\chi2/df = 2.486$, incremental fit index (IFI) = 0.985, Tucker-Lewis index (TLI) = 0.978, comparative fit index (CFI) = 0.985, root-mean-square error of approximation (RMSEA) = 0.062 and root mean square residual (RMSR) = 0.014. Additionally, the overall Cronbach's alpha value was 0.941, while the Cronbach's alpha value of each dimension was also above 0.8, that is, CL (0.916), MCL (0. 899) and SML (0.885), confirming that the reliability of the instrument was also acceptable. The composite reliability (CR) for each dimension was also above 0.7: CL (0.917), MCL (0. 900) and SML (0.886).

Facilitating conditions

The facilitating condition instrument was adopted and adjusted from Lai et al. (2012) and G. Zhao et al. (2021). This instrument consists of six items. Four items were designed to examine students' perceived emotional and technical availability from teachers and peers (e.g., "Teachers encourage employing ICTs for digital informal learning" and "Peers share tips on employing ICTs for digital informal learning"). Two items on the availability of infrastructures and resources (e.g., "My college or university offers sufficient infrastructures related to digital informal learning, which can meet my learning needs"). The confirmatory factor analysis results revealed that the standardised factor loadings of items ranged from 0.733 to 0.821. Furthermore, the fit index of the instrument was acceptable, with $\chi2 = 21.355$, df = 6, p value = 0.002, $\chi2/df = 3.559$, IFI = 0.990, TLI = 0.974, CFI = 0.990, RMSEA = 0.082 and RMSR = 0.016. The reliability was also confirmed, with Cronbach's alpha = 0.909 and CR = 0.910.

Digital competence

The instrument to examine students' digital competence was adopted from Mehrvarz et al. (2021). The instrument had three dimensions (TS, CS and EK) – specifically, five items on TS (e.g., "I can solve software and hardware failures through online searching"), four items on CS (e.g., "I can evaluate the reliability of information obtained from the Internet") and four items on EK (e.g., "I often pay attention to protecting my privacy information when surfing the internet"). Items were answered on a 5-point Likert scale, ranging from 1 (*completely disagree*) to 5 (*completely agree*). Three items (i.e., TS3, CS3 and EK2) were removed due to their low factor loadings. After deleting the items, the standardised factor loadings of the remaining 10 items were above 0.5 (ranging from 0.597 to 0.957). Furthermore, the fit index of the instrument was acceptable (Hu & Bentler, 1999), $\chi2 = 130.753$, df = 31, p value = 0.000, $\chi2/df = 4.218$, IFI = 0.960, TLI = 0.942, CFI = 0.960, RMSEA = 0.092 and RMSR = 0.042.

Additionally, the overall Cronbach's alpha value was 0.894, while the Cronbach's alpha value of each dimension was also above 0.8, i.e., TS (0.844), CS (0.888) and EK (0.877), confirming that the instrument's reliability was also acceptable. The CR for each dimension was also above 0.7: TS (0.825), CS (0.908) and EK (0.883), meeting the criterion recommended by Hair et al. (1998).

Technostress

The instrument of technostress was adopted and adjusted from Ayyagari et al. (2011). This part includes four items, for example, "I feel that my personal life has been invaded by digital technology" and "I have to change habits to adapt to new developments in digital technology". One item (i.e., TeS4) was removed

because of its low factor loadings. The standardised factor loadings of the remaining items were between 0.735 and 0.861. The reliability was also acceptable, with Cronbach's alpha = 0. 852 and CR = 0.854.

Table 2
The validity and reliability of the instruments

Variables	Items	Loadings	CR	AVE	α
Facilitating conditions	FC1	0.815	0.910	0.628	0.909
	FC2	0.733			
	FC3	0.821			
	FC4	0.815			
	FC5	0.816			
	FC6	0.748			
Digital competence			0.758	0.752	0.894
Technological skills		0.706	0.825	0.549	0.844
	TS1	0.597			
	TS2	0.596			
	TS4	0.891			
	TS5	0.832			
Cognitive skills		0.783	0.908	0.771	0.888
	CS1	0.712			
	CS2	0.957			
	CS4	0.943			
Ethical knowledge		0.657	0.883	0.719	0.877
	EK1	0.911			
	EK3	0.91			
	EK4	0.706			
Digital informal learning			0.884	0.926	0.941
Cognitive learning		0.866	0.917	0.786	0.916
	CL1	0.856			
	CL2	0.920			
	CL3	0.883			
Metacognitive learning		0.940	0.900	0.751	0.899
	MCL1	0.898			
	MCL2	0.833			
	MCL3	0.867			
Social and motivational learning		0.881	0.886	0.661	0.885
	SML1	0.776			
	SML2	0.819			
	SML3	0.873			
	SML4	0.781			
Technostress	TeS1	0.735	0.854	0.662	0.852
	TeS2	0.861			
	TeS3	0.839			

Results

The measurement model

Detailed confirmatory factor analysis results in Table 2 indicated that the reliability for both measurement models (i.e., first- and second-order models) is acceptable. The coefficients of Cronbach's alpha and CR were all greater than the 0.70 threshold (Fornell & Larcker, 1981). Furthermore, the convergent validity (Table 3) was also acceptable, with average variance extracted (AVE) values above 0.5 and the square root value of AVE being greater than the paired intercorrelations (Chin, 1998). The fit index of both measurement models was also acceptable, the first-order model ($\chi 2$ = 156.606, df = 48, *p* value = 0.000,

χ2/df = 3.263, IFI = 0.959, TLI = 0.944, CFI = 0.959, RMSEA = 0.077 and RMSR = 0.029), the second-order model (χ2 = 631.542, df = 287, *p* value = 0.000, χ2/df = 2.200, IFI = 0.954, TLI = 0.948, CFI = 0.954, RMSEA = 0.056 and RMSR = 0.35).

Table 3
Descriptive statistics and intercorrelations between variables

Variables	Mean	SD	1	2	3	4	5	6	7	8
Facilitating conditions	3.629	.687	.792							
Technological skills	3.830	.652	.247	.741						
Cognitive skills	3.681	.663	.387	.446	.878					
Ethical knowledge	4.221	.613	.354	.333	.391	.848				
Cognitive learning	3.514	.744	.489	.386	.426	.302	.887			
Metacognitive learning	3.584	.685	.430	.425	.376	.314	.756	.867		
Social and motivational learning	3.517	.665	.495	.477	.413	.328	.656	.752	.813	
Technostress	2.799	.771	-.025	-.238	-.134	-.116	-.080	-.126	-.102	.814

Hypotheses testing

The research model was verified by employing the PROCESS macro for SPSS. The PROCESS macro is developed to test models of mediation and moderation (Hayes, 2013), which was widely used in previous studies (Liu et al., 2017; Verkijika, 2019). To test the hypotheses, we employed Model 5 of the PROCESS macro, specifically developed to test the model conceptualised in this study in which both mediation and moderation effects on a given relationship are calculated (Hayes, 2013). Options were set as follows: bootstrap sample size = 5000, confidence level for confidence intervals = 95%.

Model A calculated the effect of facilitating conditions on students' digital competence after controlling for the influences of gender and grade. The results indicated that both gender (β = 0.032, $p > 0.05$) and grade (β = 0.003, $p > 0.05$) have no significant influence on students' digital competence while facilitating conditions (β =.306, $p < 0.01$) have a significant positive effect on students' digital competence, supporting H2. Model A accounted for an 18.1% variance in digital competence.

Model B presented the effect of facilitating conditions on students' DIL after controlling for the influences of gender, grade, digital competence,and technostress. Similar to the result of Model A, both gender (β =- 0.017, $p > 0.05$) and grade (β = 0.001, $p > 0.05$) have no significant influence on students' DIL. In terms of the main variables, both facilitating conditions (β = .605, $p < 0.01$) and digital competence (β = .536, $p < 0.01$) have positive significant effects on students' DIL, thus supporting H1 and H3, respectively.

Additionally, the interaction effect of Facilitating conditions x Technostress is negative and significant (β = -0.106, $p < 0.05$), proving that technostress negatively moderated the effect of facilitating conditions on students' DIL and supporting H5. The PROCESS macro also evaluates this interaction by calculating the conditional effect of facilitating conditions on DIL with low, mean, and high levels of technostress. The results revealed that the significant effect of facilitating conditions on DIL is lowest when technostress is high (effect = 0.227, $p < 0.01$) and increases when technostress is at a mean level (effect = 0.309, $p < 0.01$) while further increasing to a more decisive effect once technostress is low (effect = 0.391, $p < 0.01$). Thus, H5 was supported. The moderating effect of technostress is shown in Figure 2.

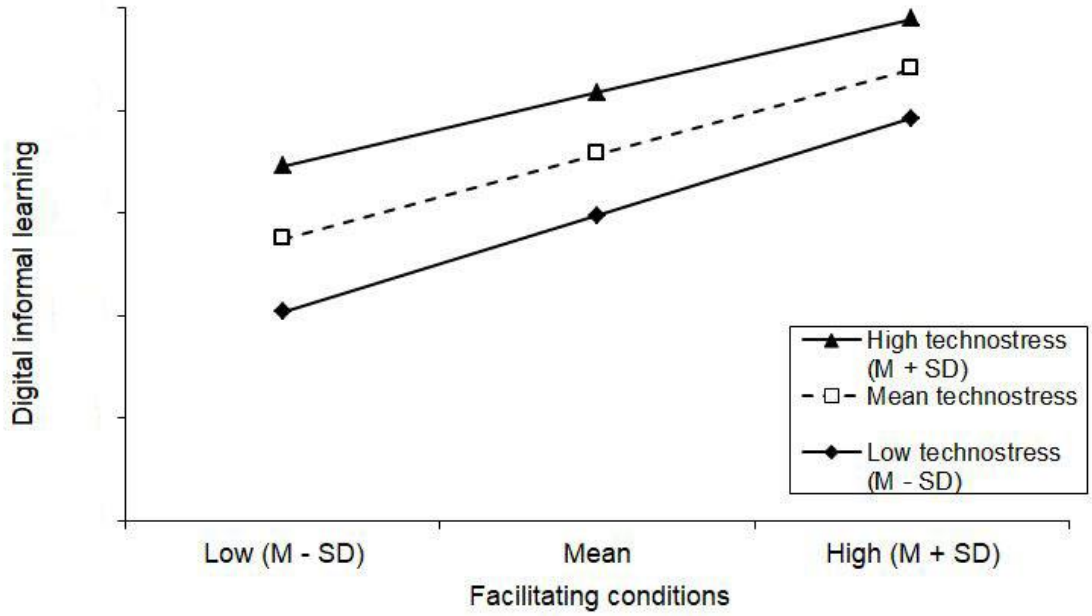

Figure 2. Facilitating conditions x Technostress for DIL

Finally, the PROCESS macro also examined the indirect effect of facilitating conditions on DIL through digital competence. As seen in Table 4, the indirect effect of facilitating conditions on DIL is positive and significant (index = 0.164, 95% CI = [0.106, 0.233]), supporting H4. Model B accounted for a 43.2% variance in DIL. The results of the structural model are presented in Figure 3.

Table 4
Analysis of the research model

Model	**Model A (DV = Digital competence)**			**Model B (DV = DIL)**		
Construct or variable	β	SE	*t* value	β	SE	*t* value
Constant	2.737	.149	18.323**	-.745	.517	-1.442
Gender	.032	.046	.699	-.017	.049	-.339
Grade	.003	.021	.133	.001	.022	0.006
Facilitating conditions	.306	.033	9.145**	.605	.124	4.867**
Digital competence				.536	.056	9.608**
Technostress				.390	.167	2.339*
Facilitating conditions x Technostress				-.106	.043	-2.449*
R^2	.181			.432		
F	28.131**			47.954**		

Conditional direct effects analysis (Facilitating conditions → DIL)					
	Effect	Boot SE	*t* value	Boot LLCI	Boot ULCI
Low technostress	.391	.049	7.877**	.293	.488
Mean technostress	.309	.039	7.857**	.232	.386
High technostress	.227	.053	4.259**	.122	.332

The indirect effect of Facilitating conditions on DIL			
Effect	Boot SE	Boot LLCI	Boot ULCI
.164	.032	.106	.233

Note. DV: dependent variable; Boot LLCI: bootstrap lower limit of the confidence interval; Boot ULCI: bootstrap upper limit of the confidence interval.
$*p < 0.05$. $**p < 0.01$.

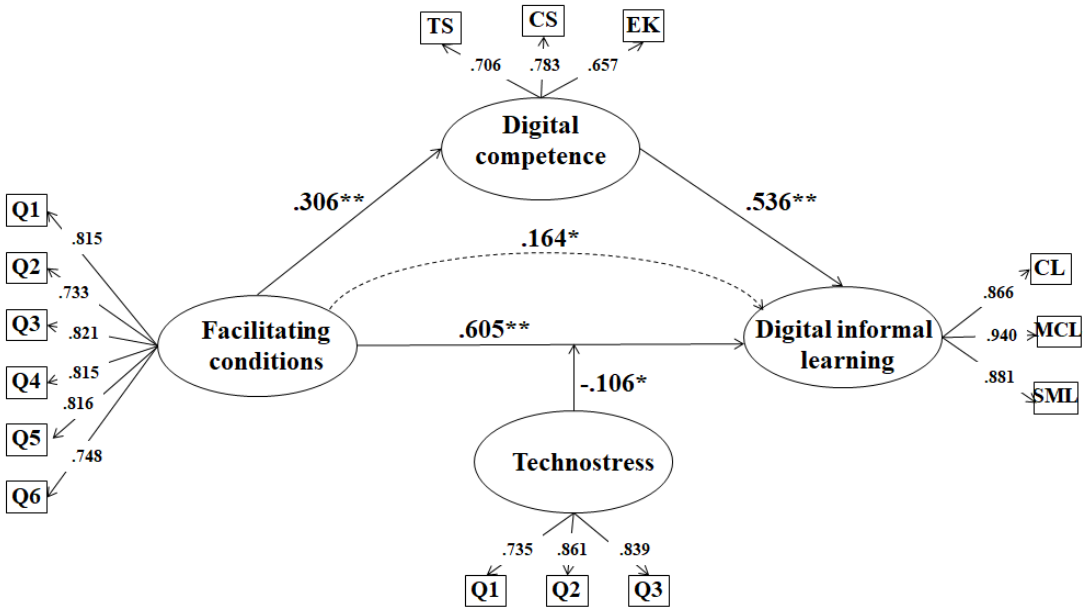

Figure 3. Results of the structural model

Discussion

This study investigated how facilitating conditions provided by colleges or universities influence students' DIL. A conceptual model considering digital competence's mediating role and technostress's moderating role was proposed and confirmed with a sample of 385 undergraduates. The notable findings are the following:

The important role of facilitating conditions on DIL

The results revealed that facilitating conditions positively predict undergraduates' digital competence and DIL. Therefore, we can argue that sufficient facilitating conditions would better enable higher education students to develop knowledge and skills related to ICT usage, organise the learning process, seek learning motivation and acquire comprehensive knowledge. This finding is consistent with previous studies for different educational contexts and subjects (i.e., Al Shamsi et al., 2022; Alshammari & Alshammari, 2024; Han & Geng, 2023). For instance, Abbad et al. (2009) found that technical support is important to students' adoption intention of e-learning systems. Similarly, Groves and Zemel (2000) reported that positive support provided by organisations is rated as a critical factor influencing teachers' adoption of instructional technologies in teaching. Conversely, a lack of sufficient infrastructure (e.g., computers) is a common obstacle preventing individuals from using technology (Mehlinger & Powers, 2002). Students' DIL requires relevant infrastructure, resources and support (Mehrvarz et al., 2021). The importance of facilitating conditions on DIL is manifested at least in the following two aspects: firstly, the accessibility and efficiency of technical infrastructure and resources provide physical environments for students to develop digital competence and engage in DIL; secondly, the support provided by teachers and peers can improve students' perceived ease of use of a given technology, which may, in turn, enhance digital competence and DIL (Al Shamsi et al., 2022).

The mediating effect of digital competence

The results also indicated that students' digital competence positively affects DIL, suggesting that students with higher levels of ICT-related knowledge and skills are more likely to use technologies for learning outside the formal educational system. This result aligns with previous studies (e.g., Mehrvarz, 2021), which also reported a positive association between digital competence and DIL. Higher digital competence enables individuals to learn more from DIL (Elstad & Christophersen, 2017; Jin, 2019). For

instance, student teachers' digital competency significantly contributes to their instructional self-efficacy in the context of technology-rich settings (Elstad & Christophersen, 2017). It must be recognised that students are not inherently aware of how to use technology to serve learning in an effective way (Niu et al., 2022). Digital competence is crucial in promoting students' DIL, especially in the current situation of huge prosperity and uneven quality of digital resources. Firstly, digital competence can help students deal with the challenges in DIL by empowering them with the capabilities to search, identify, evaluate, exchange and create digital information, enabling them to identify the learning resources that match their needs and enable them to cooperate with others successfully. Secondly, digital competence can effectively alleviate students' exhaustion and cynicism during the process of digital learning (Niu et al., 2022), making the experience of DIL easier and more comfortable. In the end, students' willingness to DIL may increase. Finally, for individuals with higher digital competence, their high achievement in DIL may lead to high participation in DIL, enabling them to achieve goals through DIL, forming a virtuous cycle.

The moderating effect of technostress

The results also revealed that technostress negatively moderates the association between facilitating conditions and DIL, signifying that the positive effect of facilitating conditions on DIL decreases when technostress increases. This result aligns with Verkijika (2019), who reported that technostress has a negative and significant moderating effect on the relationship between the perceived usefulness and continuance intention to use digital textbooks. This finding provides a possible explanation for studies (e.g., Morrison & Camargo-Borges, 2016; Teo, 2011) that did not find the positive impact of environmental conditions on technology use for learning, suggesting that technostress is a potential influencing boundary factor. As the dark side of ICT usage, technostress negatively impacts students' academic productivity (Qi, 2019; Upadhyaya & Acharya, 2020) and even leads to learning burnout in technology-enhanced learning (G. Zhao et al., 2021). We provide a possible explanation for the negative moderating effect of technostress on the association between facilitating conditions and DIL. In the context of DIL, students' technostress may arise due to the following reasons: incapability to adapt to the technologies and incompatibility between their prior learning habits and DIL. Thus, for students with high levels of technostress, learning with digital technology may be an unnatural and uncomfortable experience. Consequently, they may resist adopting DIL even under friendly external conditions.

Contributions, implications and limitations

From a theoretical perspective, the present study makes three contributions. First, although studies have pointed out that sufficient instructional support can facilitate students' technology use for learning in different contexts (e.g., Alshammari et al., 2024; El-Gayar & Moran, 2006), few studies have been concerned about its impact on students' DIL. This study empirically confirms the important role of facilitating conditions in enhancing graduate students' DIL. Second, to our knowledge, the indirect effect of facilitating conditions on students' DIL through digital competence is a new association. Although existing studies have found that digital competence is a predictor of DIL (e.g., He & Zhu, 2017), this study highlights the importance of digital competence because it not only influences DIL directly but also positively mediates the effect of facilitating conditions on DIL. Third, this study may be an initial attempt to propose and test the boundary effect of technostress in the relationship between facilitating conditions and DIL. This is a new insight that reminds subsequent researchers to consider technostress to refine existing models of DIL; especially since there are mixed findings regarding the association between DIL and its predictors.

From a practical perspective, the findings suggest several practical implications associated with DIL. Firstly, effective measures should be taken to provide friendly conditions for students' DIL, especially emotional, technical and pedagogical support. For instance, universities and colleges could organise DIL-sharing activities to encourage teachers and students to share excellent learning resources and strategies of DIL, forming a positive atmosphere for DIL. Adequate infrastructures, such as computers and stable and high-speed networks, should be equipped to meet the needs of students in DIL. Secondly, administrators should recognise the importance of students' digital competence and create sufficient

opportunities for their development, provide students with diverse elective courses associated with technology so that they can choose according to their needs, time and interests, and implement effective strategies (e.g., reward and peer assistance), which motivate students to update their technological knowledge and keep up with technology development. Thirdly, considering the existence of technostress and its adverse moderating effects on students' DIL, students need to make schedule their learning appropriately when implementing DIL to avoid experiencing too much technostress. Doing some physical activities and seeking technical help are suitable for dealing with technostress (Zhai et al., 2020). Additionally, administrators should be aware of the existence of technostress and take adequate measures to alleviate its negative consequences, such as guiding students to view emerging technologies as opportunities for personal growth and encouraging them to seek technical help or social support actively when encountering technical difficulties (Q. Wang & Yao, 2021; Zhang et al., 2019).

Due to conditional constraints, this study has some shortcomings and areas that could be improved. First, since the sample of this study is limited to Chinese students and the sample size is not large enough, the findings may not be entirely applicable to students in other countries or areas. Second, although the variables proposed in this study explained 43.2% of the variance in students' DIL, the remaining portion remains uncaptured in the current model. Future work may need to consider the effects of some other variables, such as personal factors (e.g., innovativeness, habit) (He & Zhu, 2017) and environmental factors (e.g., school climate) (Jaafari et al., 2012).

Conclusion

To better understand students' DIL in higher education, this study proposed digital competence as a possible mediator and technostress as a potential moderator in the association between facilitating conditions and DIL. The findings provide a relatively sound understanding of how facilitating conditions impact DIL. These confirm that facilitating conditions contributed to students' DIL in two ways: by facilitating DIL directly and by enhancing their digital competence. Technostress exerts a negative moderating effect on the association between facilitating conditions. To enhance higher education students' DIL, educators should take effective measures to provide sufficient environmental support, develop students' digital competence and help students to cope with technostress.

Author contributions

Author 1: Conceptualisation, Investigation, Writing – original draft, Writing – review and editing; **Author 2**: Data curation, Investigation, Formal analysis, Writing – review and editing; **Author 3**: Investigation, Writing – original draft.

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