How does Internet access quality affect learning outcomes? A multiple mediation analysis among international students in China

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ABSTRACT

The study explored how the quality of Internet access influenced students' online learning experiences during the pandemic-imposed large-scale adoption of online education. Drawing upon digital inequality research, we analyzed data collected from 894 higher education international students in China. We found that both access devices and Internet stability exerted significant impacts on international students' satisfaction with and performance of synchronous online learning (SOL). The path model further revealed that the underlying mechanisms through which the two dimensions of access inequality affected learning outcomes were different. While the effects of access devices on learning satisfaction and course performance were only mediated by adaptability to online pedagogy, Internet stability affected the two outcome variables via both interaction and adaptability. The study highlights the implications of these findings in the context of online education.

Keywords: mobile-only users, Internet stability, synchronous online classes, learning outcomes, International students

Online learning, as an umbrella term, often means online education, is distinguished from face-to-face learning in terms of time, technology, physical distance and education context (Singh & Thurman, 2019). Prior to the COVID-19 pandemic, online learning had only been employed as an optional supplement to in-person classes in most countries; unexpectedly, it has become the only

solution for the education sector to ensure continued learning during the pandemic and may last a long time in post-pandemic era especially for international students in higher education (Komolafe et al., 2020). Owing to campus closure and long-time travel restrictions, they have to rely on distance learning for a long time. Compared with domestic students, distance learning is particularly challenging for international students due to issues related to time zone differences, communication tools, language and a lack of multicultural content (Liu et al., 2010). In the context of internationalization of higher education, there were over 6 million internationally mobile students in 2019, up from 2 million in 2000 (UNESCO's Institute for Statistics, 2021). While traditionally it is the western countries being the leading destinations for international students, there is increasing competition from some destinations in East Asia such as China, Japan and Korea which are keen to attract foreign students. Take China as an example, the number of international students has grown steadily after 2003 and in 2018 there were nearly 500,000 international students in China (China Ministry of Education, 2019), partly due to the reforming in China's higher education system as well as the implementation of "One Belt and One Road" strategy [1]. Given the huge difficulties caused by the pandemic for international education, empirical investigations targeted at this group of students would be informative.

Within the long evolution of distance learning, students' satisfaction and performance have constantly been the focus of educational researchers and practitioners, the two outcome variables which are of paramount significance in promoting successful educational process. Among various determinants of these two learning outcomes, technological issues including course or program design, facilitation, technical tools were one of the primary studied antecedents (Kauffman, 2015; Martin et al., 2020; Rasheed et al., 2020). However, over the years, online education has mainly been treated as a good-to-have alternative (Ribeiro, 2020). As a supplement tool or an option, the presupposition of these studies is that participants engaged in virtual classes already have sufficient technological equipment and reliable Internet access. As a result, previous literature has mostly focused on the effects of detailed course design or learning environment on learning outcomes and paid little attention to the impact of the more fundamental accessibility issue. Notably, due to the COVID-19 pandemic, the role of online learning has been sharply changed from the good-to-have alternative to serious-mission model in order to continue educational activities. Under this new circumstance, it is important to reconsider the role of basic technology infrastructure in students' learning experiences. Coupled with the rapid diffusion of Internet technologies, an undeniable fact is that digital inequality remains severe and not all students have access to all digital devices and high-quality Internet (van Deursen & van Dijk, 2019). Problem related to Internet access was the most prevalent problem encountered during online learning (Chen et al., 2020; Chung et al., 2020; Komolafe et al., 2020).

Significance of this study

While preliminary research has identified infrastructure inadequacies in adapting to contemporary learning modalities, there is scant empirical evidence on its impact on student online learning experiences—an increasingly pertinent issue as online education surges post-pandemic. Therefore, drawing upon the digital inequality research, the current study aims to improve our understanding of how Internet access quality influences students' learning satisfaction and performance by using survey data collected from 894 higher education international students in China who enrolled in synchronous online learning (SOL) during the COVID-19 pandemic. This study is pivotal as it examines the potential constraints on online education access and efficacy due to varying technological resources across regions. It also contributes to the digital inequality discourse by elucidating the correlation between internet access quality and student learning satisfaction and outcomes.

Specifically, two dimensions of access quality are examined: uses of different devices and perceived Internet stability. In addition to examining the effects of access devices and Internet stability on outcomes of SOL, we further investigate whether these relationships are mediated by students' interaction behaviors (i.e., student-content and student-instructor interaction) as well as their adaptability to online pedagogy. These mediators are proposed in that interaction is an indispensable requirement for learning in any education settings and the ability to adjust to new forms of class is a vital predictor of learning outcomes in changing education conditions (Holliman et al., 2019; Komolafe et al., 2020; Zhang et al., 2021). Based on existing literature, the current study addresses the following questions:

(1) How do access devices and Internet stability affect students' satisfaction with and performance of SOL?
(2) Can student-content, student-instructor interaction and adaptability to online pedagogy explain the effects of access devices and Internet stability on students' satisfaction with and performance of SOL?

LITERATURE REVIEW

From "access divide" to "access quality"

The digital divide or digital inequality, originally describing the gap between so-called Internet have and have-nots, has been a serious issue studied for over twenty years (Bonfadelli, 2002; van Dijk, 2005). Digital inequality can take many forms with the revolution in Internet technologies, such as access divide, skill divide and outcome divide (Khan et al., 2020). As a result of digital inequality, the unequal preparedness for the digital education revolution holds both within and between countries, which has raised deep concerns among researchers and practitioners during the speedy implementation of online education (Adedoyin & Soykan, 2023; Dhawan, 2020; van de Werfhorst, 2021; van de Werfhorst et al., 2020). As described, online learning is entirely dependent on technological

devices and Internet, and those with low-quality digital tools and Internet connection would encounter great difficulties in gaining successful educational practices (Dhawan, 2020).

The two forms studied here are uses of different devices and stability of Internet connection, belonging to access inequality or the first level digital divide. In recent digital inequality research, an increasing number of scholars have shifted their focus from the binary access divide to the more complex forms of access (Correa et al., 2020; Marler, 2018; Tsetsi & Rains, 2017; van Deursen & van Dijk, 2019). In this vein, the "device divide" has received extant scholarly attention given the sharp rise in mobile Internet users in both developed and developing countries. Relative to people who can have Internet access via laptop or desktop personal computers (PCs), mobile-only users face greater barriers due to technological limitations of smartphones in terms of screen size, content availability, platform and network openness, memory and interface functionalities, etc., representing an inferior form of Internet access or "second-class citizens online" (Murphy et al., 2016; Napoli & Obar, 2014). These differences between mobile and PC-based forms of Internet access can reinforce and even exacerbate inequalities in user engagement, content creation and digital skills (Napoli & Obar, 2014). For example, Pearce and Rice (2013) found that mobile-only users were less likely to engage in work-related activities, using search engines and reading news online but more likely to use social networking sites. By using data of 2681 Internet users in Chile, Correa and colleagues (2020) have revealed that mobile-only users are related to lower levels of digital skills and less diverse types of uses of Internet compared with those who also use PCs after controlling socio-economic characteristics.

Regarding educative situation, some experimental studies have found that screen size does make a significant difference regarding student's performance (Kim & Kim, 2012; Park et al., 2018). An experiment ran in authentic teaching sessions with 483 first-year higher education students revealed that the use of laptops provided better results in terms of students' engagement with the videos and satisfaction with the devices (Albó et al., 2019). Participants in this study have commented that having a bigger screen offers more comfort for watching audiovisual contents. The smaller screen sizes, greater scrolling requirements as well as reduced functionality of smartphones or tablets result in an increased cognitive burden (Napoli & Obar, 2014), yet enrolling in SOL is a cognitively demanding activity and requires effective and in-depth usage of Internet. Thus, we expect that mobile-only users would have lower levels of learning satisfaction and performance than PC users.

The above-mentioned experimental studies on screen size have ensured that students have similar Internet connection status, however, in real settings, learners' Internet stability varied greatly. Slow and unreliable connectivity pains both students and teachers frequently (Amadara, 2020). In the current study, apart from the device issue, we also explore how Internet stability affects learning outcomes. Online learning relies on both technological devices and reliable Internet connection, and students with bad Internet connection are liable to be denied or delayed access to learning platforms (Adedoyin & Soykan, 2023). In

addition, compared with other services, SOL using video conferencing or streaming video service has put forward higher requirements for Internet connection, due to its real-time characteristics. It should be noted that previous studies of device gap have not carefully investigated the connection issue, since most of them assumed that the device gap had already covered the connection disparities. That is, it is often assumed that using a smartphone to access the Internet means a worse and unreliable connection. However, with the rapid updating of mobile network generation i.e., from 3G to 5G as well as the advancement in the functionalities of smartphones or tablets, the quality of mobile-access Internet is not necessarily lower than that of PC connection. In developing countries, many international students may own PC devices but still be in lack of reliable Internet connection (Ahmadani, 2020). Therefore, we consider the device issue and connection issue as two different factors and examine whether they exert independent effects on learning outcomes. Generally, with PC devices and reliable Internet connection in online learning, learners tend to have better viewing quality and comfortability, and more detailed tasks can be conducted.

The mediating role of interaction

An interaction is commonly understood to depict actions among individuals, but scholars also extend it to include individual interactions with course content (Bernard et al., 2009; Hrastinski, 2009; Truhlar et al., 2018). According to Moore (1989), interaction in any educational context falls into one of three forms: student-content, student-instructor, and student-student interaction. This study considers student-content and student-instructor interaction, since student-student interaction is less common in live virtual classes. Student-content interaction refers to the process of intellectually interacting with the content that may result in changes in learner's knowledge. Generally, one-way communication behaviors such as reading information texts, using study guidelines and watching videos could be regarded as student-content interaction (Bernard et al., 2009). Student-instructor interaction traditionally focuses on classroom-based dialogues between the two agents. In synchronous classes, student-instructor interaction may be synchronous through telephone calls, videoconferencing, and chats, or asynchronous through email, discussion board and correspondence.

In any form, interaction is an integral component of quality distance education. The benefits of learner interaction, including positive effects on satisfaction and retention, and on learning achievements and other aspects, are almost taken for granted. There is convincing empirical evidence that supports such statements. For example, a meta-analysis of 74 studies revealed that all three types of interactions were positively associated with increased achievement outcomes of online learning (Bernard et al., 2009). The affective benefits of interaction are also evidenced. Prior studies have found that interaction is highly associated with the learning effectiveness of online courses and most students who reported higher levels of interaction with content, instructor, and peers showed

higher levels of satisfaction as well as achievements (Eom, 2009; Goh et al., 2017; Kuo et al., 2013).

Scholars also devoted efforts to explaining why student interacts in virtual classes, from technological designs to the interactive functionality, neglecting the basic access issue. Nevertheless, the effect of Internet access quality on student-content and student-instructor interaction seems quite straightforward. Prior digital inequality research has confirmed that mobile-only users are in a disadvantaged position regarding their breadth and depth in Internet use (Pearce & Rice, 2013). The smaller screen sizes and greater scrolling requirements are highly associated with the decreased level of perceived ease of use and increased levels of perceived task difficulty, which in turn, lead to less engagement with content and instructor; similarly, network congestion can make students lose their interest in content quickly and drop out easily. To conclude, the lack of sufficient Internet access could reduce students' interaction with content and instructor, which further decrease students' satisfaction with and performance of SOL. Therefore, interaction behaviors could be one potential mediating mechanism between Internet access quality and learning outcomes.

The mediating role of adaptability

Adaptability refers to an individual's appropriate cognitive, affective and/or behavioral adjustments in the face of new, changing or uncertain situations or events (Martin et al., 2012, 2013). Despite the limited literature examining these relations in online education settings, adaptability is theorized to influence students' course satisfaction and academic achievement (Martin et al., 2012, 2013). Learners who are higher in adaptability scale are more likely to monitor, control and adjust their emotions, cognitions and behaviors to more effectively deal with the task, overcome difficulties and achieve better performance as a result (Martin et al., 2013). Prior empirical investigations mostly conducted in the face-to-face educational setting and consistently suggested that students' adaptability positively predicted their satisfaction (Holliman et al., 2018) and academic achievements (Burns et al., 2018; Collie et al., 2017) among various academic stages. Given the unplanned switch from face-to-face learning to online learning after the outbreak of COVID-19 pandemic, in the current study, we examine students' domain-specific adaptability, that is, adaptability to online pedagogy rather than general ability. As for domain-specific measures, student adaptability in mathematics was found to be a significant predictor of their mathematic achievements (Collie & Martin, 2017). In line with these studies, we assume that less adaptable students tend to be less satisfied with SOL and get lower course scores.

There is a scarcity of literature that explored the influences of access devices and Internet stability on students' adaptability to online pedagogy. But it is logical to infer that with better access condition or technical support, it would be easier for students to adapt themselves to online pedagogy. Smaller screen sizes or poor-quality connection may limit the ability of students to fully comprehend and follow the instructions from teachers. Given that we anticipate links from Internet

access quality to adaptability, and from adaptability to learning outcomes (i.e., satisfaction and achievement), adaptability to online pedagogy is supposed to be another significant mediator that could explain the effect of Internet access quality on learning outcomes.
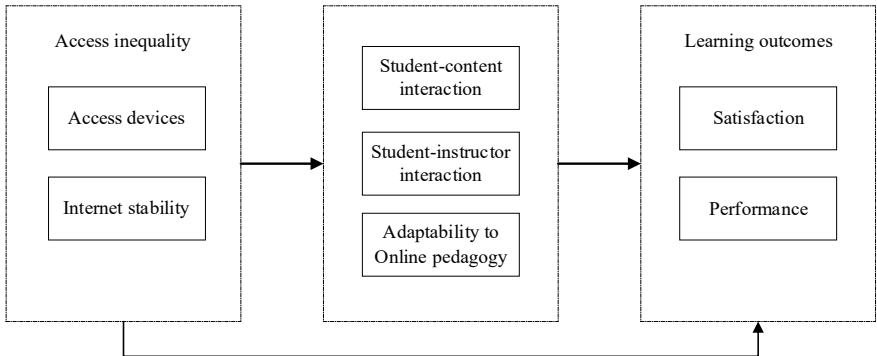
The research model is presented in Figure 1.

Figure 1: The research model

METHOD

Data Collection

The study employed data from Survey of Higher Education International Students in China, an online survey that explored Chinese international students' life and education experiences during and after the COVID-19 pandemic. The survey was conducted in three universities in China between April 2020 to March 2021 via https://www.wjx.cn/, a professional online data collection website. In order to have a reasonable geographic representation of international students, the selected three universities were different in their types and locations. The first one is a science and engineering university located in Western China, the second is a normal university located in Eastern China and the third is a comprehensive university located in Central China. The research team cooperated with the Institute of International Education and distributed the link of the questionnaire via WeChat groups of international students in each school. The questionnaire was presented in three languages - Chinese, English and French and consisted of seven subsections. There was one question designed for quality control at the end of some subsections. For example, it asked participants to choose the picture which presented "The Great Wall". Most students answered the questionnaire in English and the final valid sample was 1183 with 730 cases coming from the first university, 281 cases from the second and 172 cases from the third. We excluded participants who did not enroll in any synchronous online classes in the spring semester of 2020, which results in a total of 894 study subjects for our analysis. The descriptive statistics was shown in Table 1.

Table 1: Descriptive Statistics (*N* = 894)

Variables	Categories	Frequency	%
Age	18~20	136	15.21
	21~30	649	72.60
	31~40	102	11.41
	41~50	7	0.78
Gender	Female	370	41.39
	Male	524	58.61
SES	Under class	15	1.68
	Lower middle-class	147	16.44
	Middle class	508	56.82
	Upper middle-class	194	21.70
	Upper class	30	3.36
Location during 2020 spring semester	China	406	45.41
	Asia (except China)	397	44.41
	Africa	53	5.93
	Other continents	38	4.25
Top3 sending countries	India	148	16.55
	Pakistan	127	14.20
	Iran	48	5.4
University	The one in West China	521	41.87
	The one in East China	239	47.29
	The one in Central China	134	10.84
Education stage	Prep/Non-degree	35	3.91
	Undergraduates	477	53.36
	Postgraduates	213	23.83
	PhD candidates	169	18.90
Scholarship	No	320	35.79
	Yes	574	64.21
Private learning space	No	262	29.31
	Yes	632	70.69
Number of online courses	1~3	154	17.23
	4~6	400	44.74
	7~9	122	13.65
	Over 10	218	24.38

Measures

Independent variables

Access devices. The survey asked students whether they had the following devices in their dormitory or at home during the spring semester of 2020 (0 = *no*, 1 = *yes*): computer (including personal computer and laptop), tablet and smartphone. Those who were only able to use tablets or smartphones to access Internet were defined as mobile-only users (n = 300, 33.59%, coded as 0), and others were defined as PC & mobile users (n = 594, 66.44%, coded as 1) including

those who could only access Internet through computers (25.62%) and those who owned both types of devices (40.83%).

Internet stability. Students were asked to indicate how reliable their Internet connection was during live classes (including fixed broadband or mobile broadband) on a 5-point scale (1= *always stuck*, 2 = *occasionally stuck*, 3 = *generally*, 4 = *smooth*, and 5 = *very smooth*; M = 3.143, SD = 1.090).

Mediators

Student-content interaction. Students were asked "did you keep engaging with the course content during the whole live class?" on a 5-point scale (1 = *never* to 5 = *always*; M = 3.992, SD = 1.122).

Student-instructor interaction. Students were asked "did you maintain proper interactions with the teacher during or after online courses?" on a 5-point scale (1 = *never* to 5 = *always*; M = 3.633, SD = 1.256).

Adaptability to online pedagogy. On a 5-point scale, students were asked to indicate whether they could be adaptable to the online teaching methods (1 = *not adapted*, 2 = *not quite adapted*, 3 = *about average*, 4 = *mostly adapted*, and 5 = *fully adapted*; M = 3.348, SD = 1.096).

Dependent variables

Satisfaction. Students were asked to indicate how satisfied they were with the online courses in the spring semester of 2020 on a 5-point scale (1= *very dissatisfied*, 2 = *mostly dissatisfied*, 3 = *neither satisfied nor dissatisfied*, 4 = *mostly satisfied*, and 5 = *very satisfied*; M = 3.529, SD = 1.076).

Performance. Students were asked to choose the final average grade for all online classes they received during the spring semester of 2020 on a 5-point scale (1 = *fail – less than 60*, 2 = *pass – 60~69*, 3 = *good – 70~79*, 4 = *very good – 80~89*, and 5 = *excellent – 90~100*; M = 3.865, SD = 0.962).

Control variables

Control variables include age, gender, subjective family socioeconomic status (SES), location during 2020 spring semester, current educational stage, whether the student received a scholarship and owned a private learning space, the number of online courses they attended and which university they belonged to (See in Appendix for descriptive statistics).

Analytical strategies

First, the study performed all the descriptive statistics and other preliminary analyses in Stata 15.1. Then, the study employed structural equation model (SEM) in Mplus 7.4, using path analysis with observed variables. In SEM, the relationships among the independent, mediating and dependent variables are accessed simultaneously through covariance analysis. Maximum likelihood (ML) method was used to estimate the parameters. The study used bootstrapping

procedure to test mediating effects as it makes no assumption about the nature of the sample distribution of the statistic. In addition, it tests multiple mediations simultaneously, allowing for better appreciation of the complete effect (Hair et al., 2014; Hayes, 2018). We employed 5,000 interactions of the bootstrapping procedure to estimate the 95% bias-corrected confidence interval for the total indirect effect and the indirect effects of each path (Hayes, 2018).

RESULTS

Preliminary analysis

Table 2 shows the mean differences of Internet stability, student-content interaction, student-instructor interaction, adaptability to online pedagogy, satisfaction with and performance of SOL by access devices. In general, mobile-only users owned poorer Internet stability. It is also shown that those with lower levels of interaction and adaptability were more likely to be mobile-only users. Similarly, those reported lower score on satisfaction and performance tended to be mobile-only users. Table 3 presents the correlation matrix between the core studied variables. Internet stability was significantly and positively correlated with the three mediators – student-content interaction, student-instructor interaction and adaptability. Internet stability was also positively correlated with students' satisfaction with and performance of SOL.

Table 2: Mean differences by access devices

	Mobile-only users (n=300)	PC & mobile users (n=594)	*t*	*sig*
Internet stability	2.877 (1.042)	3.278 (0.045)	-5.271	***
Student-content interaction	3.767 (1.193)	4.106 (1.068)	-4.311	***
Student-instructor interaction	3.393 (1.305)	3.754 (1.214)	-4.091	***
Adaptability	3.053 (1.105)	3.497 (1.062)	-5.814	***
Satisfaction	3.233 (1.106)	3.678(1.030)	-5.950	***
Performance	3.663 (0.993)	3.966 (0.930)	-4.494	***

Note. Standard deviation in parentheses

Table 3. Correlations between the core variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) Internet stability	1.000					
(2) Student-content interaction	0.312	1.000				
(3) Student-instructor interaction	0.362	0.517	1.000			
(4) Adaptability	0.402	0.393	0.528	1.000		
(5) Satisfaction	0.332	0.338	0.501	0.560	1.000	
(6) Performance	0.215	0.262	0.299	0.277	0.279	1.000
Mean	3.143	3.992	3.633	3.348	3.529	3.865
SD	1.090	1.122	1.256	1.096	1.076	0.962

Note. All the correlations are significant and *p*<0.001.

SEM analysis

Table 4 demonstrates the standardized coefficients for total, direct and indirect path effects after controlling students' sociodemographic characteristics. As indicated, the total effects of access devices and Internet stability on the two outcome variables were all significant. In particular, both access devices and Internet stability had significant and positive effects on students' satisfaction with SOL. Compared with mobile-only users, PC & mobile users had better performance; those who owned better Internet stability also tended to have better performance.

Table 4. Total effect, direct effect and indirect effect of Internet access quality on learning outcomes

Paths	Coef. (SE)	Bias-corrected 95% confidence interval
Total effect		
PC & mobile users→ satisfaction	**0.105 (0.032)**	**[0.043, 0.168]**
Internet stability→ satisfaction	**0.254 (0.033)**	**[0.190, 0.318]**
PC & mobile users→ performance	**0.099 (0.036)**	**[0.029, 0.169]**
Internet stability→ performance	**0.164 (0.037)**	**[0.089, 0.235]**
Direct effect		
PC & mobile users→ satisfaction	**0.064 (0.028)**	**[0.009, 0.119]**
Internet stability→ satisfaction	**0.079 (0.030)**	**[0.019, 0.138]**
PC & mobile users→ performance	**0.077 (0.035)**	**[0.012, 0.166]**
Internet stability→ performance	0.071 (0.039)	[-0.008, 0.145]
Indirect effect (Total)		
PC & mobile users→ satisfaction	**0.041 (0.013)**	**[0.008, 0.072]**
Internet stability→ satisfaction	**0.175 (0.021)**	**[0.136, 0.218]**
PC & mobile users→ performance	**0.022 (0.010)**	**[0.004, 0.042]**
Internet stability→ performance	**0.093 (0.017)**	**[0.062, 0.129]**
Indirect effect (Specific)		
PC & mobile users→ SCI → satisfaction	0.002 (0.003)	[-0.001, 0.010]
PC & mobile users→ SII→ satisfaction	0.010 (0.008)	[-0.004, 0.027]
PC & mobile users→ AOP→ satisfaction	**0.029 (0.001)**	**[0.008, 0.051]**
Internet stability→ SCI → satisfaction	0.008 (0.008)	[-0.006, 0.024]
Internet stability→ SII→ satisfaction	**0.060 (0.012)**	**[0.039, 0.086]**
Internet stability→ AOP→ satisfaction	**0.107 (0.015)**	**[0.080, 0.141]**
PC & mobile users→ SCI → performance	0.007 (0.005)	[0.000, 0.021]
PC & mobile users→ SII→ performance	0.005 (0.005)	[-0.002, 0.017]
PC & mobile users→ AOP→ performance	**0.009 (0.005)**	**[0.002, 0.023]**
Internet stability→ SCI → performance	**0.027 (0.011)**	**[0.009, 0.050]**
Internet stability→ SII→ performance	**0.032 (0.013)**	**[0.010, 0.060]**
Internet stability→ AOP→ performance	**0.033 (0.014)**	**[0.007, 0.064]**

Note. Estimates are standardized coefficients; bootstrap based on 5,000 resamples; bolded values represent paths that are statistically significant; SCI = student-content interaction, SII = student-instructor interaction, AOP = adaptability to online pedagogy.

Figure 2 shows the standardized coefficients of all the direct paths, including all the direct associations between independent variables and mediators as well as the relationships between mediators and learning outcome variables. As presented, compared with mobile-only users, PC & mobile users showed a higher level in adaptability to online pedagogy ($\beta = 0.084$, $p < 0.01$) but not in the two types of interaction. Internet stability was positively associated with all the three mediators – student-content interaction ($\beta = 0.230$, $p < 0.001$), student-content interaction ($\beta = 0.252$, $p < 0.001$) and adaptability to online pedagogy ($\beta = 0.306$, $p < 0.001$). Then, it is shown that students' satisfaction with SOL was predicted by student-instructor interaction ($\beta = 0.239$, $p < 0.001$) and adaptability ($\beta = 0.350$, $p < 0.001$) but not by student-content interaction. All the three mediators were positively and significantly related to performance of SOL. Overall, as shown in Table 3, the effects of access devices on satisfaction with and performance of SOL were partially explained by the mediators since both the direct path and indirect path were significant, so did the effects of Internet stability on satisfaction. Contrarily, the direct effect of Internet stability on performance was insignificant, indicating that the effect of Internet stability on performance was completely explained by the mediators.
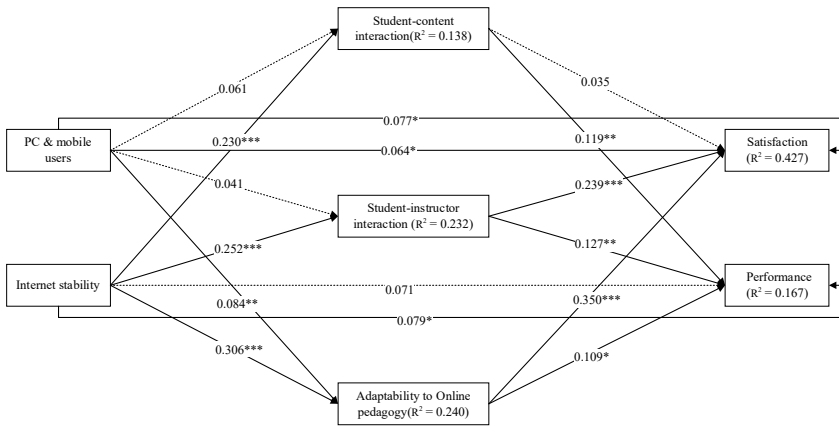

Figure 2. Results of the path analysis.

Note. Estimates are all standardized coefficients. Age, sex, SES, location, college, current study stage, scholarship, private learning space and number of online courses were entered as exogenous variables, but not shown here. Dotted arrow denotes insignificant paths. *p < 0.5, **p<0.01, ***p<0.001.

Regarding the specific indirect effects of each path, the results in Table 3 show that student-content interaction and student-instructor interaction were not significant processing mechanisms through which access devices influenced satisfaction with SOL, whereas adaptability was a significant mediating

mechanism between access devices and satisfaction with SOL (β = 0.029, 95% CI = 0.008, 0.051). As for the association between Internet stability and satisfaction, student-instructor interaction (β = 0.060, 95% CI = 0.039, 0.086) and adaptability to online pedagogy (β = 0.107, 95% CI = 0.080, 0.141) were significant mediating mechanisms. Regarding the performance of SOL, it is found that only adaptability (β = 0.009, 95% CI = 0.002, 0.023) explained the association between access devices and performance of SOL. The three mediating mechanisms were all significant when explaining the effects of Internet stability on students' performance.

DISCUSSION

The COVID-19 pandemic marked the first time that it was mandatory for all courses to be taught online, leading to the adoption of online education on a largest scale that the world has ever seen. The large-scale and compulsory adoption raises the urgent question related to the fundamental Internet infrastructure – technological devices and reliable Internet connection – rather than the improvements in technical details, as robust Internet infrastructure is a prerequisite for online learning (Ayebi-Arthur, 2017). Given that the sudden change has left no or very limited time for the governments, educational institutions, families to bridge the existing digital inequality, the present study focuses on the basic accessibility issue and tests how the quality of Internet access affects student satisfaction with and performance of SOL. It advances existing online learning literature by empirically examining the influence of both access devices and Internet stability on online learning outcomes and the processing mechanisms underlying these associations. Besides, it is one of the very few studies that focus on international students, who have to rely more on distance education than domestic students due to the long-time travel restrictions.

Main findings

First, this study found that the two dimensions of access quality had significant predictive power in students' learning outcomes. Students with PC devices and reliable Internet connection tended to report higher levels of learning satisfaction and performance. Our finding confirms the importance of moving from the simple yes/no assess divide to the quality and consistency of connectivity which are crucial to interpreting what access can actually offer. The result is consistent with the literature offering links between access devices and Internet usage (Correa et al., 2020; Tsetsi & Rains, 2017; van Deursen & van Dijk, 2019) as well as experimental studies exploring the relationship between screen size and learning outcomes (Albó et al., 2019; Park et al., 2018). Mobile-only Internet use is increasingly common especially for entertainment and social purposes. However, in the domain of education, such preference seems to be marginalized and practices remain firmly attuned toward PC devices. Besides, beyond the device differences that have been studied extensively, we investigated another essential dimension of access quality – the own/lack of a reliable Internet

connection. The results showed that the two access dimensions exerted independent effects on online learning outcomes among international students, indicating the necessity of exploring the independent effects of the two access dimensions with the advancement in mobile functionalities.

The second finding is that the lack of reliable Internet connection had detrimental effects on student-content interaction, student-instructor interaction and learners' adaptability to online pedagogy, whereas differences in devices only led to differences in students' adaptability but not to interaction behaviors. The null effects of mobile devices on interaction behaviors may be explained by the social attributes of mobile devices. Although representing an inferior form in many domains, people tend to get used to this type of devices for social interactions due to their mobility and convenience. Therefore, although the use of small screen devices might limit the comfortability of students' learning experience, it did not necessarily reduce their interaction behaviors. However, note that Internet stability affected all the learning process variables, suggesting the vital role that Internet stability played during the online learning processes. While the device divide was the focus of previous literature, further studies should pay more attention to the connection issue in educative situations.

Furthermore, our result provides fresh empirical evidence about the effects of interaction and adaptability on outcomes of SOL. First, as we distinguished between student-student and student-instructor, the findings revealed that only student-instructor had a positive effect on learners' satisfaction with SOL, while both types of interaction were significant predictors of their course scores. This finding is plausible in that student-content interaction belongs to one-way communication behaviors which do not need much emotional engagement, resulting in less affective benefits than cognitive benefits. Second, in offline education, adaptability was a major determinant of learning outcomes especially during a period of great changes (Collie et al., 2017; Holliman et al., 2019). Our finding is consistent with offline education research and suggests that adaptability was a major determinant of both satisfaction with and performance of SOL.

The most important finding in this study is about the mediating roles of interaction and adaptability in the relationship between Internet access quality and outcomes of SOL. The result showed that the processing mechanisms varied by the different dimensions of access inequality. While the effects of access devices on learning satisfaction and course performance were only mediated by student adaptability to online pedagogy, Internet stability affected the two learning outcomes indirectly through both interaction and adaptability. In other words, adaptability played a more robust mediating role in the relationship between the two dimensions of access inequality and learning outcomes. More empirical investigations should be conducted on the adaptability theory given that significant and interrelated social changes occur concomitantly with vital changes in higher education.

Implications

Our study offers several theoretical implications. Firstly, it contributes to a more comprehensive understanding of the relationship between Internet access quality and outcomes of SOL by consolidating different dimensions of Internet access quality and two types of learning outcomes in one integrated model. In doing so, the strengths of their impacts become comparable. Secondly, this study is among the first to introduce the interaction and adaptability mechanisms to understand how Internet access quality affects outcomes of SOL. While past studies often focused on the direct impacts of screen size on learning outcomes, our findings highlight that possible mediating effect of altered learning habits should not be ignored. Thirdly, our study contributes to addressing the research gap regarding the effects of Internet stability on outcomes of SOL. The significance of having a reliable Internet connection is frequently noticed by practitioners but very few scholars empirically examined the consequence of an unreliable Internet connection.

Overall, the study suggests the uniqueness of Internet access quality in relation to higher education international students' experience of SOL, allowing us to make a few suggestions for practitioners. It reinforces the idea that great institutional awareness should be paid on Internet infrastructure inadequacy, especially in less developed countries and rural areas. For example, in the 46 UN-designated least-developed countries, mobile broadband subscription per 100 people was 33 and the fixed broadband per 100 people was just 1 (International Telecommunications Union, 2021). Although in recent years, Internet infrastructure is developing rapidly worldwide, many developing countries and their residents still face numerous obstacles to maximize the potential of Internet with insufficient Internet access. Such is the case in online learning domain. Students from less developed countries, rural areas, or with poor socio-economic status are more likely to encounter infrastructure inadequacy during online education. This inadequacy, such as the functional constraints of mobile devices and the lack of reliable Internet connection, act as significant barriers to adopt SOL and for gaining expected benefits from technology. To conclude, given the existing global and domestic digital inequality, the large-scale and compulsory adoption of online education is highly likely to result in a rich-get-richer effect, widening educational inequality.

With its real-time nature, the synchronous online class puts forward higher requirements for access quality. In this case, it may not be the most appropriate way to continue educational activities for higher education international students. Instead, the blended class or other asynchronous online education may be more suitable as these forms proposed lower requirements on the access quality. The severe educational difficulties faced by international students serve as an urgent call for local governments to develop Internet infrastructure to minimize the possibility of being in a doubled-disadvantage position for some international students due to the pandemic and infrastructure inadequacy.

Limitations

Several limitations of this study should be noted, which also imply possible avenues for future studies. First, although researchers have justified single-item measures due to practical constraints such as respondent burden or survey length, the general consensus is that multiple item measures have better psychometric properties than single-item measures. Future research should consider using more refined measures. Second, apart from device and connection issues, the effects of other material access such as the ownership of peripherals (e.g., additional screens and docking stations) that make Internet use more convenient could be examined specifically. Third, it is better to use reports from teachers or student transcripts on student performance for cross-validation. Fourth, our study focuses on international students, a comparative analysis between international students and domestic students is highly valuable to confirm if the effects of Internet access quality on outcomes of SOL are different between the two groups. We see an urgent need to carry out such analysis in order to identify possible strategies of distance learning that work best for international students at a time when international education suffered a devastating blow. Lastly, a cross-sectional dataset was used in this study, and it does not allow for causal inferences. In this light, a longitudinal analysis of this topic may offer new insights.

Note

[1] "One belt and One Road" is a global infrastructure development strategy adopted by the Chinese government in 2013. Its emphasis on fostering relations has led to connecting various regions through education (Liang & Wang, 2021). For example, a 10-year plan is announced to provide 30,000 scholarships to students from the members of countries of the Shanghai Cooperation Organization to study at Chinese university.

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