



New challenges in mitigating climate change: Digital teaching for the sustainable development and innovation

Xin Zhao^a, Fangxia Pan^a, Xiaowei Ma^b, Syed Ali Raza^{c,d}, Xiaoxiao Zhou^{b,*}

^a School of Statistics and Applied Mathematics, Anhui University of Finance and Economics, Bengbu, China

^b School of Finance, Anhui University of Finance and Economics, Bengbu, China

^c Department of Business Administration, IQRA University Karachi, 75300, Pakistan

^d Adnan Kassar School of Business, Lebanese American University, Beirut, Lebanon

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ABSTRACT

The phenomenon of climate change has become a global challenge that affects human activities in many ways. Exploring the sustainability and innovativeness of digital education is an important reference for the further implementation of science and education strategies and positive effects on climate change mitigation. This study designed two questionnaires for basic and tertiary education to address variability in education and collected 523 samples for basic education and 412 samples for tertiary education respectively. Using digital teaching practices and digital teaching quality as mediators, structural equation modelling (SEM) was used to examine the impact of digital education on sustainability and innovation in education. Research shows that digital teaching and learning in basic and higher education can significantly contribute to the two-way development of educational sustainability and innovation, through digital teaching and learning practices. Digital teaching practice and digital teaching quality in higher education play a complete mediating role, while basic education only plays a partial mediating role. Higher education emphasizes digital teaching and learning practice processes and teaching quality, and most students hope that online teaching and learning can be further integrated with offline education to form a new model of education. This study will help government departments understand the pedagogical reality of digital education at a deeper level and provide ideas for the subsequent sustainable development and educational innovation of digital teaching. It can also provide new ideas for climate change mitigation and sustainable development.

1. Introduction

Climate change is one of the most serious global problems since the industrial revolution, sustainable development and the building of an ecological civilization have become an inevitable trend in human society development [1]. In the context of the current multiple paradoxes of widening social and economic inequalities, climate change, overexploitation of the Earth's resources, loss of biodiversity, sustainable development and innovation in education are key ways to address these deep-rooted problems. The sustainable development of education is closely linked to national science, technology and innovation, providing the country with a steady flow of innovative talent through the introduction of new tools, technologies and modes of production, with a view to providing the core

* Corresponding author.

E-mail addresses: zhaoshin_1993@163.com (X. Zhao), 1810827604@qq.com (F. Pan), maxiaowei_16@163.com (X. Ma), syed_aliraza1@hotmail.com (S.A. Raza), zxx19910410@126.com (X. Zhou).

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energy for the realization of the low-carbon transition and the transition to a resource-efficient economy. From the UN General Assembly's "Transforming our world: the 2030 Agenda for Sustainable Development" proposing to "ensure equitable, quality education and promote lifelong learning opportunities for all" to China's "China's Country Program for the Implementation of the 2030 Agenda for Sustainable Development" setting out the goals and tasks of sustainable development of education at different stages of education, the strategic position of sustainable development and innovation of education in the goal of sustainable human development is further highlighted. With the advent of the Internet age and the impact of the New Crown Epidemic, digital teaching and learning solves the problem of educational sustainability in the context of the Epidemic, and at the same time effectively responds to the "choke point" of global sustainable development.

Online teaching not only plays an emergency role during the pandemic but is also a learning revolution and innovation in the field of education and teaching that China has been committed to promoting in recent years. Governments, international organizations, enterprises, and universities worldwide are urgently exploring effective ways to transform traditional teaching into a new model of digital teaching. Finally, it has made preliminary achievements in the field of digital teaching and ensured the "closing the school and not stopping learning" during the epidemic situation [2]. By 2021, 100% of primary and secondary school students in China will have access to the Internet, 99.5% of schools will have multimedia classrooms, and a ubiquitous learning environment will basically be formed, with complete network coverage and the integration of offline multimedia teaching spaces and online teaching spaces, education informatization has moved from the 1.0 era to the 2.0 era, creating favorable conditions for the in-depth implementation of the digitalisation strategy for basic education. The value logic of digital empowerment in promoting high-quality development of education is mainly reflected in the integration of governance to construct an integrated education system, which provides stronger support for education to achieve digital governance and educational reform. It also offers a digital education platform and online resources for education, enhancing sustainable development and innovation capability in education. The National Medium and Long-term Education Reform and Development Plan (2010–2020) and the China Education Modernization 2035 both list the promotion of education informatization as an important development goal; the National Informatization Plan for the 14th Five-Year Plan also clearly states for the first time that "lifelong digital education will be carried out, and education and lifelong learning services at all levels will be continuously expanded and optimized"; the 20th National Congress once again emphasized accelerating the implementation of the innovation-driven development strategy, strengthening basic research, and encouraging free exploration. China's pursuit of sustainable development and innovation in education continues. Online teaching has been comprehensively promoted through the educational experience of the "novel coronavirus epidemic." This global situation has led to a reflection on the future of online teaching. If online teaching is implemented to solve urgent problems during the pandemic, then how can online teaching platforms be better used after the pandemic is fully lifted? Can digital teaching and learning contribute to sustainable development and innovation in education in the current context of global climate change?

In this context, this study uses a questionnaire to explore this topic in depth. The theoretical significance of this study is that it explores whether digital teaching can promote sustainable development and innovation of teaching based on teaching reality, make up for the missing perspective on the relationship between digital teaching and educational development and innovation in the education industry research, and provide new research thinking for education sustainability research. Its practical significance is that it can provide new ideas for government departments to understand the teaching and learning situation of digital education at a deeper level and improve the scale of the education system, which can further explore the digital potential of digital education and deepen education reform based on this study.

The structure of the latter part is as follows: the second section introduces the literature review and research hypothesis; the third section introduces the research method and process of this study; the fourth section presents the data analysis and research results, descriptive statistical analysis, reliability analysis, and variable relationship tests on the questionnaire data; and the fifth section presents the empirical conclusion and policy implications obtained.

2. Literature review and research hypothesis

2.1. Digital teaching before the epidemic

Online education is considered a form of distance education, a teaching method featuring e-learning that relies on computer network technology to deliver information from the instructor to participants through Internet technology [3]. Online education is spaceless, accessible, and convenient for digital teaching, which reduces the costs of time and money. Meanwhile, the sharing and communication features of digital education considerably promote educational equity, create ample space for students and teachers to exchange and discuss, and provide inclusivity in education [4–6]. Several scholars have discussed digital education before the pandemic, and some believe that it is an inevitable challenge and a driving force for change that can replace traditional education in the global network [7,8]. Although online education is more commonly used in higher education in China, traditional face-to-face teaching is still practiced in basic education. Moreover, online teaching is not widely recognized, and many students only experience digital teaching through multimedia classrooms, electronic courseware, online completion of assignments, and other teaching forms [9].

2.2. Digital teaching in the context of COVID-19

The rapid outbreak of COVID-19 affected different sectors globally including public health, political, economic, cultural, and educational. Among all sectors, the educational system is bound to be the hardest hit. According to the United Nations Educational,

Scientific, and Cultural Organization (UNESCO), the COVID-19 outbreak has affected nearly 1.6 billion students in more than 190 countries, including students from different countries [10–14], different majors [15–18], and different stages [19–23]. COVID-19 has caused many challenges globally, including overall governance capacity, education level, construction capacity, and level of education informatization of a country [24]. In response to the lack of learning opportunities caused by the suspension of classes, several countries have focused on distance education. However, while overall internet user penetration is 51.2 %, only 45 % is observed in developing countries and 20 % in the least-developed countries, according to the 2019 State of the World Broadband Report. When the pandemic began, network facilities and information technology in most countries were still developing and some basic problems and challenges remained in online education [25]. Examples of the challenges include inadequate infrastructure and technology, academic climate, digital disconnect, psychological fallout, media disruptions, and digital illiteracy, which need to be urgently addressed in digital education to accelerate the adaptation to online classes [24].

In response, several scholars conducted extensive research during the pandemic on addressing educational challenges and maximizing current opportunities [26–30]. Studies have shown that due to the emergency rollout of online education, a lack of time for training and online simulations occurred and many teachers and students did not have time to adapt to the new teaching model [31]. In the face of the challenges, some scholars have proposed that teachers adjust course subjects, change teaching methods, and become proficient in online teaching facilities. Moreover, students were encouraged to adjust their learning mentality, gradually adapt to the external environment, and enhance their self-learning ability. Schools and parents are required to provide a good learning atmosphere for digital teaching according to the needs of the situation, such as the learning environment, unobstructed network, and adequate teaching facilities [32,33]. On the one hand, the rapid change to digital education caused poor psychological satisfaction for students. On the other hand, digital teaching provides many favorable methods for education during the epidemic [17]. Due to the comprehensive development of online teaching, the advantages of digital education are also gradually presented in practice, and due to its flexibility and being spaceless, some of the phenomena such as unequal educational opportunities and the digital divide have been greatly alleviated, which gradually increased the level of online education [34]. Additionally, digital resources are more comprehensive; a digital classroom allows visualization of dull information; the education form is more novel; and, to a certain extent, the digital promotion has innovated the status quo in education [35].

2.3. Digital teaching and education sustainability and innovation

Although the idea of sustainable development and innovation in education is not new, it is also the righteous goal of people at all educational levels. Education for Sustainable Development (ESD) is recognized as the primary goal of UNESCO, established in 1992 (UNESCO Agenda 21), and has continued support from the United Nations (Education for a Sustainable Future: Environmental Population and Development Programme, 1992). Education is considered a means to improve the quality of life, contribute to the development of society, and also an important factor in promoting sustainable human development [36,37]. In recent years, innovation has been encouraged in various industries, including technological and industrial innovation. The challenges and opportunities of globalization and technological development have increased the emphasis on innovation as a key driver of sustainable economic development; however, without educational innovation, social innovation will also be difficult to achieve [38,39]. The pandemic reveals that by making education sustainable and innovative, global challenges can be addressed constructively and creatively, as well as provide opportunities to improve new models of education effectively [40]. The internet is key to innovation in many industries and is equally important for sustainable development and modernization in education. Online teaching during the pandemic proved that digital platforms are good for educational innovation and a breakthrough for achieving sustainable education [41]. With the pandemic coming to an end and education about to return to normal, will education integrate a new pedagogy to reduce the gap between levels of education and the needs of future generations? This may be an opportunity for the education sector to achieve qualitative breakthroughs in education [42].

2.4. Research hypothesis

In line with the 2030 Sustainable Development Goals, many scholars believed that sustainable development education could play a major role in achieving Sustainable Development Goals. Moreover, education can be a powerful force for change or a conservative force. Hence, educational innovation will be a driving force for social innovation [43]. During the pandemic, online teaching has been the emergency refuge of the education sector. Digital technology has been used to optimize the transformation of the online education experience and also to enhance traditional classroom teaching methods [44,45]. Through the full implementation of online teaching, students have cultivated learning skills and autonomy, teachers have improved the online teaching model, online social teaching equipment has been completed, it expands the learning space for students and stimulates their interest in learning, and educational institutions have gradually transferred to a broader digital field. This indicates that digital communication offers new opportunities. With a solid infrastructure, it can compensate for the traditional disadvantages of uneven distribution of educational resources, avoid monotonous face-to-face education, and break the narrow information channel where teachers are the only source of knowledge. digital learning can help the education of the country to gradually integrate into the global technological framework, promoting sustainable development and educational innovation [46].

Based on the above analysis, the following hypotheses are made in this study.

H1. Digital teaching has a significant positive impact on sustainable development and innovation in education.

Infrastructure has also improved with social and technological innovations. Although some problems occur in some areas, such as a

lack of smooth networks, insufficient electronic facilities, and insufficient proficiency in using digital tools, online teaching remains a feasible alternative [47]. With the continuous improvement of digital technology and teaching foundations, the gradual adaption of students and teachers to online teaching modes is necessary. Education from not based on the conceptual level, is through the classroom leader teacher to complete the teaching practice, to promote the operation of efficient classroom activities, to play with the students' learning initiative and interest, to achieve the innovative integration of digital and teaching practice, is a key element of education for sustainable development [48]. On the one hand, digital education facilities are the basic prerequisite for online education. A good digital teaching foundation makes it possible to solve problems in the process of educational practice in a diversified and innovative way [49]. On the other hand, teachers complete precise teaching design and scientific teaching organisation on the basis of digital teaching and learning, so as to ensure the co-creation and integration of "teacher-machine-student", to improve students' skills and develop a good personality; students use digital teaching and learning products to obtain the required resources and services, to solve the learning problems, so as to formulate an effective and reasonable learning plan. Students use digital teaching products to obtain the resources and services they need to solve their learning problems. They also make scientific and reasonable learning plans. This is the intrinsic motivation for sustainable education Educational practice is a crucial hub for digitally-enabled education sustainability, and is a key practice in the digital transformation of education for education sustainability and global sustainability [50]. Based on this, we propose the following hypothesis.

H2. Digital teaching has a significant positive influence on digital teaching practice.

H3. Digital teaching practices have a significant positive impact on sustainable development and innovation in education.

H4. Digital teaching practices play an intermediate role in digital teaching, sustainable educational development, and innovation.

Regardless of the teaching method, quality education is always the goal pursued by the education sector. Under the influence of the pandemic, the domestic education system must quickly adapt to changes to ensure that educational activities are implemented on time, specifically because the quality of education should be unaffected [51]. Firstly, by utilizing digital educational infrastructure, students can engage in seamless and extensive learning anytime and anywhere. This is achieved by providing students with integrated learning approaches that combine content acquisition, interactive methods, and non-specific learning environments [52]; At the same time, teachers optimize the teaching process and methodology through digital teaching. This involves integrating digitalisation into the profession, feeding back to students, and improving student learning efficiency and quality of teaching [53]. Furthermore, the high-quality development of education is the due meaning and inevitable requirement of the top-quality development of the economy and society, and the teaching quality of digital teaching is an extremely important performance in the digital transformation of education to promote the sustainable development of education, and the quality of teaching determines the quality of innovative talents, while high-quality talents are the promotional force for the modernization and sustainable development of education [54]. Based on this, the following assumptions are made.

H5. Digital teaching has a significantly positive impact on the quality of digital teaching.

H6. Digital teaching quality has a significant positive impact on sustainable development and innovation in education.

H7. Digital teaching quality plays an intermediate role in digital teaching, sustainable educational development, and innovation.

Related literature showed that most scholars used different methods to study opportunities and challenges, satisfaction surveys, and the advantages and disadvantages of digital education. The most basic method is a questionnaire survey, in which first-hand data are obtained to analyze the current situation. Partial least squares structural equation modeling (PLS-SEM) [55,56], SWOT analysis [57], validated factor analysis (CFA) to test hypothesis models [58], and ARDL (autoregressive distributed lag model) are also used in the study of the current status of digital education [59]. Hence, this study investigates whether digital teaching in the context of the pandemic promotes sustainable development and innovation in education using partial minimum structural equation modeling, which can avoid parameter estimation errors caused by the severely non-normal distribution of data and model fitting problems caused by sample size, collecting data in the form of a five-point closed Likert-scale questionnaire, and using two versions of the questionnaire for basic education and higher education. Moreover, our study investigates whether digital teaching and learning in the context of the pandemic advances sustainable development and innovation in education discusses how digital teaching and learning can be used in education, whether it contributes to educational innovation after the epidemic is over, and provides relevant implementable suggestions.

3. Research methodology and process

3.1. Questionnaire design

A questionnaire was used to collect data on digital education in basic and higher education during the COVID-19 pandemic to investigate its outcomes and whether it could contribute to future educational development and innovation. The questionnaire was constructed to take into account the students in basic education who generally do not have good self-learning and self-discipline skills [60], which requires distinguishing the implementation of online teaching in basic education from that in higher education; therefore, two versions of the questionnaire were set up for the two levels of education. Simultaneously, to ensure the reliability and authenticity of the questionnaire, some respondents were first pre-surveyed, and a small number of respondents were surveyed face-to-face; the questionnaire was repeatedly revised to ensure rationality.

The final two versions of the questionnaire contained four variables: digital teaching foundation, digital teaching practice, digital teaching quality, and educational sustainability and innovation, all of which were measured using a 5-point Likert scale. The higher the score, the more you agree with the content of the options, 1 to 5 means "Strongly Disagree," "Disagree," "Neutral," "Agree" and "Strongly Agree".

In the questionnaire, the digital teaching foundation mainly investigates the current digital teaching hardware facilities and external environment. The foundation of digital teaching and learning was measured by assigning scores on a 5-point Likert scale in the questionnaire. The digital teaching practice and quality questionnaire investigate the factors affecting these variables. The educational sustainability and innovation questionnaire investigates the future use intention of digital teaching and teaching satisfaction. In the age of the Internet, sustainable development and innovation in education can only be achieved through the perfect integration of digitalisation and education, and the degree of this integration is measured through the satisfaction of students and teachers and the effectiveness of education, as well as by the assignment of scores from questionnaires to measure the sustainability of development and innovation in digital education.

3.2. Sample situation

Considering the regional variability of education and the availability of data, there is a need for a comprehensive understanding of digital education empowering sustainable development and innovation in education, and it is preferable to use random sampling to take a partial sample to represent the overall programme. Compared to cluster sampling, random sampling is easier to implement, the sample is more representative, and can reduce survey error caused by other factors such as urban development. The final sample, except for Xinjiang Autonomous Region and Tibet Autonomous Region, covered almost all the regions in the sample. The sample's validity and representativeness were verified. The details of the sample are as follows: In the sample (Table 1), 560 points were distributed in the basic education survey and 538 questionnaires were returned, of which only 523 were valid. Questionnaires for elementary school students were partially filled out by their teachers on their behalf to avoid inaccurate results. A total of 523 valid questionnaires were sent, of which 245 (46.9 %) were from junior high school students, 202 (38.6 %) were for high school students, and 76 (14.5 %) were for teachers. A total of 500 questionnaires were sent to higher education and 456 were returned, of which 412 were valid, of which 58 (14.08 %) were specialists, 163 were undergraduates (39.56 %), 122 (29.61 %) were postgraduates and above, and 69 (16.75 %) were college teachers.¹

3.3. Research ideas and research methods

The variables of this study are the digital teaching foundation as the independent variable, education sustainability and innovation as the dependent variables, and digital teaching practice and quality as the mediators (Fig. 1). Hardware facilities, teaching environment, and teacher training are the foundations of digital teaching, and ensuring a good digital teaching foundation is a good start for digital teaching implementation. Digital teaching practice and digital teaching quality are the links to the goal of promoting education sustainability and innovation. We conducted a study examining whether digital teaching can promote educational sustainability and innovation during and after the COVID-19 pandemic, which can be used as a reference by relevant administrators to achieve educational sustainability.

First, descriptive and reliability validity analyses of the basic and higher education questionnaires were conducted separately using SPSS software to ensure the accuracy of the survey. Subsequently, the path coefficients and significance levels were estimated in the structural model using Smart PLS software to prove whether the hypotheses were valid. One of the basic principles of PLS-SEM is to use a series of interdependent OLS regressions to minimize the residuals of the model to achieve a high degree of accuracy in model analysis [56], whose advantages include integrating reflective and formative measurement models and achieving good results in predicting exogenous variables. The size of the sample data does not need to be large to allow resampling. Finally, to test the mediating role of digital teaching practices and quality between digital teaching foundations and educational sustainability and innovation, the mediating effect was tested by estimating 95 % confidence intervals using the bias-corrected percentile bootstrap method using 5000 samples, with statistical significance indicated if the confidence interval did not contain 0.

4. Data analysis and research results

4.1. Descriptive statistical analysis

The results of the descriptive analysis of the questionnaire are shown in Table 2, 268 were males and 255 were females, 316 belonged to rural areas, and 207 were urban dwellers. Moreover, an average value of 3.5 or higher indicates that the current digital teaching infrastructure in China is good, laying the foundation for sustainable development and innovation in education. In the higher education survey, 172 respondents were male and 240 were female, 178 respondents lived in rural areas, and 234 lived in towns. The mean values for higher education were all higher than 3.5, which also reflects the good digital teaching and learning infrastructure in higher education in China.

¹ No ethical approval was required in this study. This study focus on education related factors and does not involve any animals.

Table 1
Summary of the questionnaire sample.

Variables	Basic Education Questionnaire		Higher Education Questionnaire	
	Categories	Frequency/percent	Categories	Frequency/percentage
Gender	Males	268/51.24 %	Male	172/41.75 %
	Females	255/48.76 %	Female	240/58.25 %
Careers	Junior high school students	245/46.85 %	Specialties	58/14.08 %
	High School Students	202/38.62 %	Undergraduate	163/39.56 %
	teachers	76/14.53 %	Postgraduate and above	122/29.61 %
	–	–	High school teachers	69/16.75 %
Residence	Countryside	316/60.42 %	Countryside	178/43.2 %
	Cities& Towns	207/39.58 %	Cities & Towns	234/56.8 %

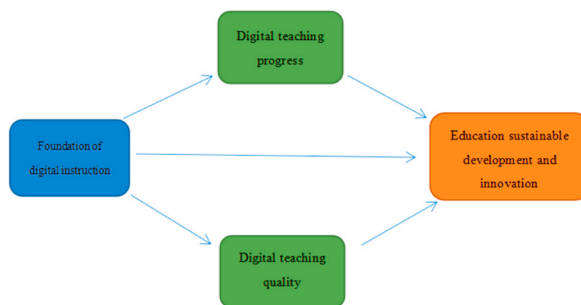


Fig. 1. | Model construction diagram.

Table 2
Results of the descriptive analysis of the questionnaire.

Variables	Basic Education Questionnaire		Higher Education Questionnaire	
	Average	Standard deviation	Average	Standard deviation
Foundations of Digital Teaching	3.797	1.078	3.692	1.030
Digital Teaching Practice	3.819	1.124	3.642	1.043
Digital Teaching Quality	3.813	1.106	3.523	1.138
Educational Sustainability and Innovation	3.793	1.116	3.639	1.132

4.2. Reliability and validity

4.2.1. Reliability and validity of higher education

We used internal consistency reliability analysis to determine whether the items used could measure similar scores. The factor load in the measurement model should be greater than 0.5; items that did not meet this condition were deleted [61]. The final test results are shown in Table 3, and the factor loadings in higher education studies were between 0.866 and 0.900. The reliability of the survey is expressed by α . The α of this questionnaire are between 0.899 and 0.944, and the calculated range of the composite reliability (CR) value for each structure is 0.929–0.955. The α needs to be greater than 0.7 and CR needs to be greater than 0.6 in the survey [62]; hence, this questionnaire is reliable. The AVE in the results ranged from 0.764 to 0.780, which met the requirement of being greater than 0.5, and the convergent validity was high [63]. The VIFs were all less than 5.000, indicating no covariance. The correlation matrix in Table 4 indicates the presence or absence of correlation between the variables; in all cases, the square root of the AVE of each variable (shown in bold along the diagonal) is higher than the corresponding correlation value for that variable (0.874–0.883), indicating good discriminant validity of the variables in this study.

4.2.2. Reliability and validity of basic education

In the same higher education reliability and validity analysis, the factor loadings of each variable range from 0.853 to 0.909 (Table 5), with all CR greater than 0.6, AVE ranges from 0.750 to 0.799, with all α also meeting the requirement of greater than 0.7, and VIF is in the range of 2.492–3.227, all less than 5. In conclusion this survey is reliable and valid. The square root of the AVE for each variable in Table 6 is higher than the corresponding correlation value for that variable (0.866–0.894), indicating that the variables in this study have good discriminant validity.

Table 3
Summary of higher education measurement model results.

constructs	Items	loadings	CR	AVE	α	VIF
Foundations of Digital Teaching	SZ1	0.882	0.955	0.780	0.944	3.118
	SZ2	0.879				3.091
	SZ3	0.879				3.141
	SZ4	0.900				3.659
	SZ5	0.883				3.536
	SZ6	0.874				3.086
Digital Teaching Practice	SJ1	0.867	0.952	0.768	0.940	3.088
	SJ2	0.877				3.053
	SJ3	0.872				2.906
	SJ4	0.878				2.988
	SJ5	0.885				3.188
	SJ6	0.880				3.273
Digital Teaching Quality	ZL1	0.870	0.951	0.764	0.938	2.961
	ZL2	0.883				3.230
	ZL3	0.867				2.801
	ZL4	0.876				3.059
	ZL5	0.866				2.929
	ZL6	0.881				3.220
Educational Sustainability and Innovation	CX1	0.871	0.929	0.766	0.899	2.533
	CX2	0.881				2.497
	CX3	0.882				2.528
	CX4	0.868				2.520

(Note: SZ indicates digital teaching foundations; SJ indicates digital teaching practice; ZL indicates digital teaching quality; CX indicates education sustainability and innovation).

Table 4
Summary of higher education discriminant validity results.

constructs	Average	Standard deviation	Foundations of Digital Teaching	Digital Teaching Practice	Digital Teaching Quality	Educational Sustainability and Innovation
Foundations of Digital Teaching	3.692	1.030	0.875			
Digital Teaching Practice	3.642	1.043	0.316	0.877		
Digital Teaching Quality	3.523	1.138	0.124	0.143	0.883	
Educational Sustainability and Innovation	3.639	1.132	0.244	0.289	0.282	0.874

Table 5
Summary of results of the basic education measurement model.

constructs	Items	loadings	CR	AVE	α	VIF
Foundations of Digital Teaching	SZ1	0.864	0.947	0.750	0.933	2.733
	SZ2	0.882				3.095
	SZ3	0.867				2.853
	SZ4	0.876				3.070
	SZ5	0.855				2.704
	SZ6	0.853				2.682
Digital Teaching Practice	SJ1	0.882	0.941	0.799	0.916	2.708
	SJ2	0.889				2.817
	SJ3	0.909				3.227
	SJ4	0.895				2.836
Digital Teaching Quality	ZL1	0.894	0.935	0.782	0.907	2.801
	ZL2	0.885				2.652
	ZL3	0.890				2.695
	ZL4	0.869				2.578
Educational Sustainability and Innovation	CX1	0.887	0.934	0.781	0.906	2.706
	CX2	0.879				2.655
	CX3	0.875				2.492
	CX4	0.893				2.761

Table 6
Summary of discriminant validity results for basic education.

constructs	Average	Standard deviation	Foundations of Digital Teaching	Digital Teaching Practice	Digital Teaching Quality	Educational Sustainability and Innovation
Foundations of Digital Teaching	3.797	1.068	0.884			
Digital Teaching Practice	3.819	1.121	0.326	0.894		
Digital Teaching Quality	3.8126	1.099	0.355	0.268	0.866	
Educational Sustainability and Innovation	3.793	1.099	0.265	0.303	0.324	0.885

4.3. Variable relationship test

Model 1 only includes the digital teaching foundation and education sustainable development and innovation. Model 2 adds digital teaching practice to Model 1 to test the mediating effect of this variable. Model 3 adds digital teaching quality variables to Model 1 to test the mediating effect of digital teaching quality on digital teaching foundation and education sustainable development and innovation. Model 4 adds digital teaching quality variables to Model 1 to test the mediating effect of digital teaching practice and education sustainable development and innovation. Finally, two mediators of digital teaching practice and digital teaching quality were added to the digital teaching foundation and educational sustainable development and innovation to verify the two-way development of digital teaching through the digital teaching practice process and digital teaching quality for sustainable development and innovation.

4.3.1. Higher education variable relationship test

In model 1, the digital teaching foundation significantly affects education sustainability and innovation. "Internet + education" in China is an effective path for teaching innovation in recent years. The delivery characteristics of digital teaching put high demands on network facilities and digital tools, and a high level digital teaching foundation significantly promotes education sustainability and innovation; hence, supporting hypothesis H1 ($\beta = 0.125$, $t = 2.528 > 1.96$). In model 4 (see Table 7 and Fig. 2), digital teaching foundation significantly affects digital teaching practice and digital teaching quality. Digital teaching practice and quality improve teaching quality based on the effective integration of Internet by the teachers and independent absorption of online teaching content by the students. In addition online teaching foundation is also an important influencing factor, and thus verifying Hypothesis H2 ($\beta = 0.143$, $t = 2.714 > 2.58$) and Hypothesis H5 ($\beta = 0.282$, $t = 5.271 > 2.58$). A more significant effect of digital teaching practices and digital teaching quality on educational sustainability and innovation is observed, supporting H3 ($\beta = 0.265$, $t = 4.718 > 2.58$) and H6 ($\beta = 0.156$, $t = 2.807 > 2.58$).

In Model 2 (see Table 8), a significant effect of digital teaching foundation on digital teaching practices was observed ($\beta = 0.145$, $t = 2.863 > 2.58$). In addition, digital teaching practices significantly affected educational sustainability and education ($\beta = 0.305$, $t = 5.617 > 2.58$). After introducing digital education practice as a mediating variable, digital education foundation did not have a significant effect on educational sustainability and innovation ($\beta = 0.080$, $t = 1.616$). In comparison to basic education, higher education is extensive, specialized, and difficult. Moreover, higher education needs to implement knowledge into preparation through digital teaching practice to promote education sustainability and innovation; hence, H4 is verified, and digital teaching practice plays a fully mediating role.

In Model 3 (see Table 8), digital teaching and learning foundations significantly affected digital teaching and learning quality ($\beta = 0.281$, $t = 5.266 > 2.58$), while digital teaching and learning quality significantly affected educational sustainability and innovation ($\beta = 0.228$, $t = 4.242 > 2.58$). After introducing digital teaching and learning quality as a mediating variable, digital teaching and learning foundations showed no significant effect ($\beta = 0.060$, $t = 1.220$). The currently available digital teaching software and facilities environment in higher education is relatively developed; improving the digital environment alone promotes digital sustainability and innovation to a limited extent. In addition, digital teaching and learning should be driven by the quality of digital education to promote educational sustainability, and thus, H7 verified that the quality of digital teaching and learning plays a fully mediating role.

4.3.2. Basic education variable relationship test

Four same models were set up in the higher education and basic education survey. In the first model, the foundation of digital

Table 7
Summary of higher education test results.

Assumptions	Specific paths	Std.Beta (β)	T-Statistics	P-Values	Decision
H1	Digital Teaching foundations -> Education Sustainable Development and Innovation	0.125	2.528	0.006	H1Confirmed
H2	Digital Teaching foundations -> Digital Teaching Practice	0.143	2.714	0.003	H2Confirmed
H3	Digital Teaching Practice -> Education Sustainable Development and Innovation	0.265	4.718	0.000	H3Confirmed
H5	Digital Teaching foundations -> Digital Teaching Quality	0.282	5.271	0.000	H5Confirmed
H6	Digital Teaching Quality -> Education Sustainable Development and Innovation	0.156	2.807	0.003	H6Confirmed

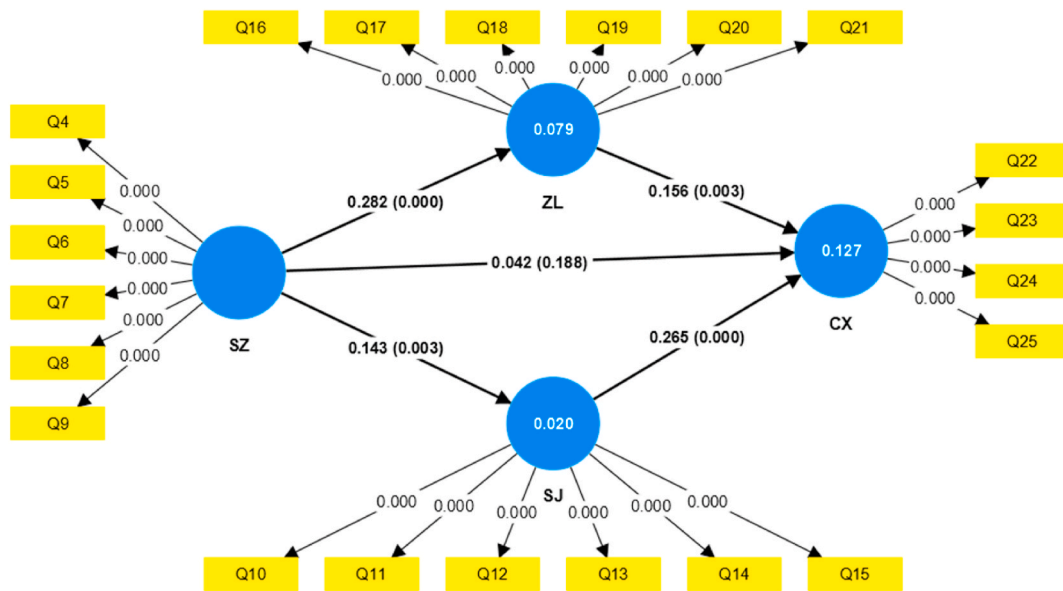


Fig. 2. Results of higher education model

Note: Numbers in represent p-values; The results were significant using the 1 % level and the following table is the same.

Table 8
Summary of higher education model pathway results.

Models	Specific paths	Std. Beta (β)	T-Statistics	P-Values	Decision
Model 1	Digital Teaching foundations - > Education Sustainable Development and Innovation	0.125	2.528	0.006	
Model 2	Digital Teaching foundations - > Education Sustainable Development and Innovation	0.080	1.616	0.053	H4Confirmed
Model 2	Digital Teaching foundations - > Digital Teaching Practice	0.145	2.863	0.002	
Model 2	Digital Teaching Practice - > Education Sustainable Development and Innovation	0.305	5.617	0.000	
Model 3	Digital Teaching foundations - > Education Sustainable Development and Innovation	0.060	1.220	0.111	H7Confirmed
Model 3	Digital Teaching foundations - > Digital Teaching Quality	0.281	5.266	0.000	
Model 3	Digital Teaching Quality - > Education Sustainable Development and Innovation	0.228	4.242	0.000	

teaching and learning significantly affects educational sustainability and innovation, thus, supporting hypothesis H1 ($\beta = 0.355, t = 7.758 > 2.58$). In model 4 (Table 9 and Fig. 3), the foundation of teaching and learning significantly affects digital teaching practices and digital teaching quality; hence, verifying hypotheses H2 ($\beta = 0.268, t = 5.484 > 2.58$) and hypothesis H5 ($\beta = 0.324, t = 6.846 > 2.58$). The digital teaching practices and digital teaching quality have a more significant impact on educational sustainability and innovation, supporting H3 ($\beta = 0.222, t = 4.537 > 2.58$) and H6 ($\beta = 0.114, t = 2.57$).

In model 2 (see Table 10), digital pedagogical foundations significantly influenced digital pedagogical practices ($\beta = 0.268, t = 5.489 > 2.58$). Digital pedagogical practices significantly influenced educational sustainability and innovation ($\beta = 0.248, t = 5.225 > 2.58$). Even after introducing digital educational practices as a mediating variable, digital pedagogical foundations still had a significant impact on educational sustainability and innovation ($\beta = 0.288, t = 6.210 > 2.58$), which was reduced compared to the path of digital education foundation on educational sustainability and innovation in model 1 ($\beta = 0.355, t = 7.758 > 2.58$), indicating that digital teaching foundation promotes educational sustainability and innovation through digital teaching and learning process. The initial integration of information-based education and basic education will promote digital education innovation to a certain extent; however, achieving

Table 9
Summary of basic education test results.

Assumptions	Specific paths	Std. Beta (β)	T-Statistics	P-Values	Decision
H1	Digital Teaching foundations - > Education Sustainable Development and Innovation	0.355	7.758	0.000	H1Confirmed
H2	Digital Teaching foundations - > Digital Teaching Practice	0.268	5.484	0.000	H2Confirmed
H3	Digital Teaching Practice - > Education Sustainable Development and Innovation	0.222	4.537	0.000	H3Confirmed
H5	Digital Teaching foundations - > Digital Teaching Quality	0.324	6.846	0.000	H5Confirmed
H6	Digital Teaching Quality - > Education Sustainable Development and Innovation	0.114	2.570	0.005	H6Confirmed

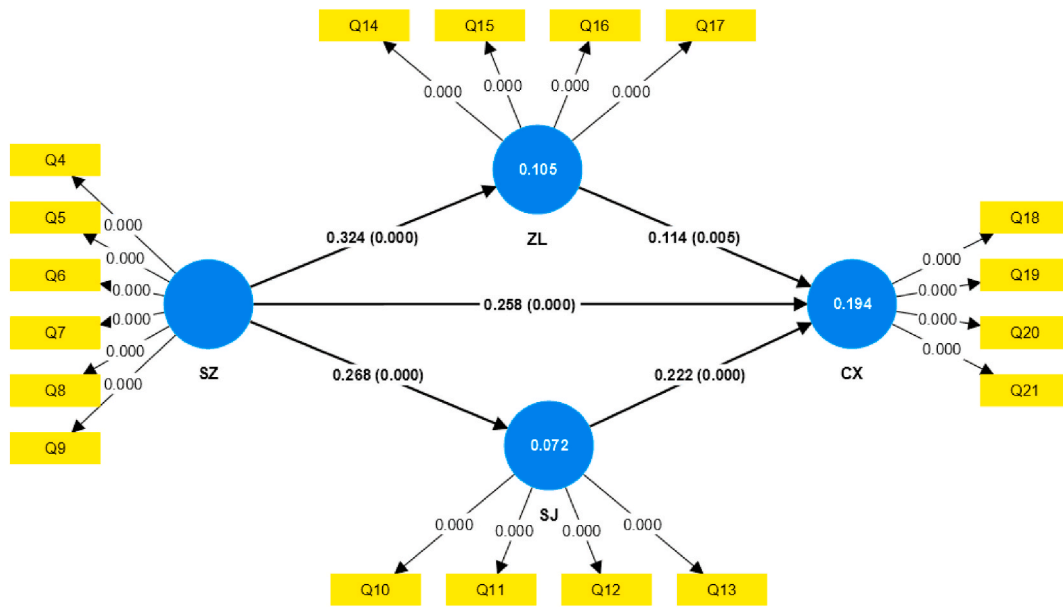


Fig. 3. Basic education model results graph.

Table 10
Summary of pathway results for the basic education model.

Model	Specific paths	Std. Beta (β)	T-Statistics	P-Values	Decision
Model 1	Digital Teaching foundations - > Education Sustainable Development and Innovation	0.355	7.758	0.000	
Model 2	Digital Teaching foundations - > Education Sustainable Development and Innovation	0.288	6.210	0.000	
Model 2	Digital Teaching foundations - > Digital Teaching Practice	0.268	5.489	0.000	
Model 2	Digital Teaching Practice - > Education Sustainable Development and Innovation	0.248	5.225	0.000	H4Confirmed
Model 3	Digital Teaching foundations - > Education Sustainable Development and Innovation	0.301	6.567	0.000	
Model 3	Digital Teaching foundations - > Digital Teaching Quality	0.324	6.852	0.000	
Model 3	Digital Teaching Quality - > Education Sustainable Development and Innovation	0.168	3.794	0.000	H7Confirmed

sustainable innovation still requires focusing on the teaching and learning process and highlighting the practical characteristics of education. H4 verifies that digital teaching and learning practices have a partial mediating role.

In model 3 (see Table 10), digital teaching and learning foundations significantly influenced digital teaching and learning quality (β = 0.324, t = 6.852 > 2.58). Digital teaching and learning quality significantly influenced educational sustainability and innovation (β = 0.168, t = 3.794 > 2.58). The introduction of digital teaching and learning quality as a mediating variable reduced the impact of digital teaching and learning foundations on educational sustainability in comparison to that of model 1. The path (β = 0.355, t = 7.758 > 2.58) is reduced, indicating that digital pedagogical foundations promote educational sustainability and innovation through digital pedagogical quality. As mentioned in China's 19th National Congress, "vigorously improve the quality of education teaching and learning to ensure that students learn enough and learn well," the high quality development of education promotes the sustainable

Table 11
Results of intermediate effect test.

Intermediary Path	Effect Value	Boot SE	LL95 %	UL95 %	Decision
Mediating Effects in Higher Education: Foundations of Digital Teaching - > Education for Sustainability and Innovation					
Direct effect: Digital Teaching Foundations - > Education Sustainability and Innovation	0.349	0.049	0.252	0.446	
Indirect Effect 1: Digital Teaching Foundations - > Digital Teaching Practice - > Education Sustainability and Innovation	0.543	0.080	0.383	0.693	H4Confirmed
Indirect Effect 2: Digital Teaching Foundations - > Digital Teaching Quality - > Education Sustainability and Innovation	0.598	0.052	0.498	0.704	H7Confirmed
Mediating Effects in Basic Education: Foundations of Digital Teaching - > Education for Sustainability and Innovation					
Direct effect: Digital Teaching Foundations - > Education Sustainability and Innovation	0.268	0.044	0.181	0.354	
Indirect Effect 1: Digital Teaching Foundations - > Digital Teaching Practice - > Education Sustainability and Innovation	0.062	0.018	0.030	0.100	H4Confirmed
Indirect Effect 2: Digital Teaching Foundations - > Digital Teaching Quality - > Education Sustainability and Innovation	0.038	0.017	0.008	0.074	H7Confirmed

development of education, and thus, H7 is verified that digital teaching quality has a partial mediating role.

4.3.3. Mediating effect test

To further test the mediating effects of digital teaching practices and quality, the bootstrap method was used. The higher education survey and the digital education foundation play a direct role in education sustainability and innovation, with a 95 % confidence interval of [0.1211, 0.2903], which does not contain 0 (Table 11). The direct effect value is 0.3489, and the effect is positive. Digital teaching is the type built on the foundation of the internet, which can enrich teaching means, improve teaching effect, and realize all-round information-based teaching. A good digital teaching environment and rich digital teaching resources can drive educational innovation, and the hypothesis H1 is verified. Digital teaching practices play a mediating role between digital teaching foundations and educational sustainability and innovation, with a 95 % confidence interval of [0.3834, 0.6934], not including 0, and an indirect effect value of 0.5425. Digital teaching requires teachers to integrate classroom teaching, practical training teaching, and information technology, as well as students changing their attitudes from "being taught" to "learning on their own." These theories implement the practical process of education in educational innovation, and thus, supporting H4. Simultaneously, digital teaching quality plays an intermediary role in the foundation of digital education and the sustainable development and innovation of education. Approximately 95 % of the intermediate intervals did not contain zero, and the indirect effect value was positive. The quality of digital teaching is of great significance and value for ensuring the sustainable development of education. High-quality digital teaching with reasonable curriculum settings, lively and interesting content, as well as easy-to-understand knowledge, can considerably promote the development and innovation of education; therefore, H7 is verified. Similarly, in basic education, the foundation of digital education promotes sustainable development and innovation in education and has been proven to have a mediating effect between digital teaching practice and quality.

5. Conclusion and implications

5.1. Research conclusions

COVID-19 has caused an educational blockade due to the total lockdown globally. Moreover, along with learning to survive the huge impact of the current global pandemic, sustainable strategies for digital teaching were developed [64]. During the pandemic, students in the vast majority of countries were taught online, which made implementation of digital education, which had existed in theory prior to the pandemic, a reality. Educational sustainability and innovation have been concerns for the education industry and even the country. Therefore, this study investigates whether the implementation of digital education can promote sustainable development and innovation in education in the context of COVID-19 and whether it can seize this pandemic change and turn the crisis into an opportunity. The results of SEM showed that all five hypotheses made for basic education questionnaire study were accepted (H1: Digital Teaching Foundations - > Educational Sustainability and Innovation, $\beta = 0.355$, $t = 7.758$, $p < 0.01$; H2: Digital Teaching Foundations - > Digital Educational Practices, $\beta = 0.268$, $t = 5.484$, $p < 0.01$; H3: digital Teaching practice - > educational sustainability and innovation, $\beta = 0.222$, $t = 4.537$, $p < 0.01$; H5: Digital Teaching Foundations - > digital Teaching quality, $\beta = 0.324$, $t = 6.846$, $p < 0.01$; H6: digital Teaching Quality - > Educational Sustainability and Innovation, $\beta = 0.114$, $t = 2.570$, $p < 0.01$), digital teaching practices and digital teaching quality as two mediating effects were also verified. In this rapidly changing technological world, online learning is a complementary approach to face-to-face classroom learning. Ultimately, the integration of emerging technologies into education is no longer an option but a requirement, specifically considering the changing learning environment characterized by the demand for flexibility in teaching and learning models, and that the online education approach in the epidemic can promote sustainable development and innovation in education and provide new perspectives for reform and innovation in basic education in China [65].

Similarly, all five hypotheses were also accepted in the higher education questionnaire study (H1: digital teaching foundations - > educational sustainability and innovation, $\beta = 0.125$, $t = 2.528$, $p < 0.01$; H2: digital teaching foundations - > digital educational practices, $\beta = 0.143$, $t = 2.714$, $p < 0.01$. H3: digital teaching practice - > educational sustainability and innovation, $\beta = 0.265$, $t = 4.718$, $p < 0.01$; H5: digital teaching foundations - > digital teaching quality, $\beta = 0.282$, $t = 5.271$, $p < 0.01$; H6: digital teaching quality - > educational sustainability and innovation, $\beta = 0.156$, $t = 2.807$, $p < 0.01$), digital teaching practices and digital teaching quality as two mediating effects were also verified. Higher education differs from basic education because it aims to train technical personnel in various industries. With the current advanced Internet smart technology in society, digital skills for higher education students will be mandatory. As Armoed (2021) stated, the COVID-19 pandemic provides a once-in-a-lifetime opportunity for higher education students to correct the irregularities and inequalities in the higher education system and address the challenges that exist with a radical, innovative, and multifaceted perspective [66].

Faced with the huge developmental potential of digital education and the strategic tasks of educational sustainability and innovation, digital teaching research still needs to be studied in depth. The next stage will further explore the impact mechanism of digital teaching, how to better promote educational sustainability, and the specific promotion path of teaching innovation, based on the research presented in this study. In terms of the role of digital education in promoting education, we will further improve the structure and teaching framework of digital teaching, bring into play the educational productivity of digital teaching, and gradually realize that educational innovation leads to technological and economic innovation.

5.2. Research implications

The pandemic has had a significant impact on educational methods and the current situation globally. For China, a developing country with a large population and a long history of traditional teaching, the impact of the epidemic on online teaching is undoubtedly the largest. The current round of online teaching processes has laid a good teaching foundation for digital teaching, and both teachers and students are gradually adapting to online teaching. More than 60 % of students are willing to continue digital teaching in the future with the new teaching norm of offline teaching in schools, supplemented by online teaching. Half or more students expressed confidence in online teaching in the future. Good teaching foundation, strictly controlled digital teaching practices, and quality as a mediator promote sustainable development and innovation in education. This study explores a sustainable innovation route for the future of digital teaching and learning and provides a new perspective for sustainable development and innovation in education (i.e. face-to-face teaching as the main focus and online teaching as a supplement to develop a new sustainable norm in education).

Based on the above research, the following insights can be drawn.

- (1) Improve online learning hardware facilities and software environments, provide a good digital environment for online teaching, and improve the quality of online teaching.

With the implementation of online teaching activities during the pandemic, China's educational informatization has achieved initial results in infrastructure and digital resource platforms; however, a gap remains between digital informatization and teaching. Perfect digital teaching conditions emphasize the value of digital resources in education and teaching. The government should understand "Internet + basic education" as a "new infrastructure" in the field of education, and make it a powerful starting point to promote education equity and improve education quality.

- (2) Change the teaching philosophy from "teaching for teaching" to "teaching for learning," focusing on the learning process of students and learning subject ability.

Society needs more personalized and innovative thinking talents, and the pandemic also reveals the shortcomings of current traditional education; students are no longer carriers of knowledge but innovators and practitioners of knowledge. Therefore, we need to transform "teaching for teaching" into "teaching for learning," highlighting the educational process and experiences of students in class, enhancing the interest of students in online learning, and strengthening their enthusiasm and initiative in independent learning.

- (3) Innovative teacher training and teaching research methods to improve online teaching design ability of teachers.

Traditional teacher training focuses on technical operations that are disconnected from the actual teaching practices. Education, as a teaching practitioner, can only feel the promoting effect of information technology on teaching through personal practices of teachers; hence, education-related departments should innovate training contents of teachers and methods to improve the deep integration of information technology and educational teaching.

- (4) Develop a new teaching model and establish a two-line integration teaching model.

Different from hybrid, integration is not simply the combination of online and traditional teaching; it is simply the allocation of knowledge corresponding to different levels of teaching objectives into different teaching forms to achieve the maximum efficiency of teaching methods, which will become the educational productivity of the economy and society of China in the online era and provide sustainable momentum for national economic development and scientific and technological innovation. Subsequent stages of teaching practice are necessary to persist.

5.3. Research shortcomings and prospects

In the context of COVID-19 and climate change, this paper explores whether digital education can promote sustainable education development and innovation, a topic related to the future. However, this research also has certain limitations. Firstly, constrained by the availability of sample data, the inability to conduct a comprehensive or as large a sample as possible, and the limited scope of the survey in each province, the sample lacks representativity; Secondly, due to the truncated nature of the time of this study, there is a lack of continuous follow-up; Finally, considering that the questionnaire should not be overloaded with questions, the measurement of digital teaching and learning and educational sustainability and innovation was not fully considered. The outlook for future research is to value the continuity of this study and continue to track data related to digital teaching and learning. This will provide data support for sustainable development and innovation in education; Furthermore, expanding the scope of the survey data to include more representative samples and addressing the lack of comprehensive coverage in the questionnaire will provide a strong empirical basis for digital teaching and learning to empower global sustainable development.

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Data availability statement

Data available on request from the authors.

Ethics statement

Ethical review and approval were not required for the study of human participants, in accordance with local legislation and institutional requirements. Written informed consent for participation was not required for this study, in accordance with national legislation and institutional requirements. The patients/participants provided online informed consent to participate in this study, which stated the voluntary nature of participation and assurance of confidentiality and anonymity.

CRediT authorship contribution statement

Xin Zhao: Writing - review & editing, Writing - original draft, Visualization, Software, Investigation, Conceptualization. **Fangxia Pan:** Writing - review & editing, Writing - original draft, Methodology, Data curation. **Xiaowei Ma:** Writing - review & editing, Writing - original draft, Formal analysis. **Syed Ali Raza:** Supervision, Resources, Investigation. **Xiaoxiao Zhou:** Visualization, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.heliyon.2023.e22829>.

References

- [1] X. Zhao, X. Ma, B. Chen, Y. Shang, M. Song, Challenges toward carbon neutrality in China: strategies and countermeasures, *Resour. Conserv. Recycl.* 176 (2022), 105959, <https://doi.org/10.1016/j.resconrec.2021.105959>.
- [2] K.B. Sumra, M. Mumtaz, N.D. Mohamed, A. Haseeb, S.H. Ansari, Online education amid COVID-19 crisis: issues and challenges at higher education level in Pakistan, *IJERI: Int. J. Eng. Res. Innovat.* 18 (2022) 240–259, <https://doi.org/10.46661/ijeri.6429>.
- [3] N. Aharony, J. Bar-Ilan, Students' perceptions on MOOCs: an exploratory study, *Interdisciplinary Journal of e-Skills Life Long Learning* 12 (2016) 145–162, <https://doi.org/10.28945/3540>.
- [4] P. Karácsony, T. Izsák, L. Vasa, Attitudes of z generation to job searching through social media, *Economics and Sociology* 13 (4) (2020) 227–240, <https://doi.org/10.14254/2071-789X.2020/13-4/14>.
- [5] I. Mustapha, N.T. Van, M. Shahverdi, M.I. Qureshi, N. Khan, Effectiveness of digital technology in education during COVID-19 pandemic. A bibliometric analysis, *International Journal of Interactive Mobile Technologies* 15 (8) (2021) 136–154, <https://doi.org/10.3991/ijim.v15i08.20415>.
- [6] F. Navaridas-Nalda, M. Clavel-San Emeterio, R. Fernandez-Ortiz, M. Arias-Oliva, The strategic influence of school principal leadership in the digital transformation of schools, *Comput. Hum. Behav.* 112 (2020), <https://doi.org/10.1016/j.chb.2020.106481>.
- [7] J. Chapman, The pragmatics and aesthetics of knowing: implications for online education, *Kybernetes* 42 (8) (2013) 1166–1180, <https://doi.org/10.1108/k-06-2013-0114>.
- [8] E.C. Hamilton, A. Feenberg, The Technical Codes of Online Education, vol. 2, *E-Learning Digital Media*, 2005, pp. 104–121, <https://doi.org/10.2304/elea.2005.2.2.1>.
- [9] J.X. Wang, D.E.H. Tigelaar, W. Admiraal, Connecting rural schools to quality education: rural teachers' use of digital educational resources, *Comput. Hum. Behav.* 101 (2019) 68–76, <https://doi.org/10.1016/j.chb.2019.07.009>.
- [10] M. Nichols, Distance and online education for VET in aotearoa New Zealand, *Reshaping Vocational Education and Training in Aotearoa New Zealand* 34 (2022) 301–312, https://doi.org/10.1007/978-3-031-12168-5_16.
- [11] A.U. Rehman, B. Khan, Challenges to online education in Pakistan during COVID-19 & the way forward, *Social Science Learning Education Journal* 6 (7) (2021) 503–512, <https://doi.org/10.13140/RG.2.2.17222.70726>.
- [12] T.K. Das, Online education during COVID-19: prospects and challenges in Bangladesh, *Space Culture, India* 9 (2) (2021) 65–70, <https://doi.org/10.20896/saci.v9i2.1220>.
- [13] T.G. Chen, L.J. Peng, B.L. Jing, C.Y. Wu, J.J. Yang, G.D. Cong, The impact of the COVID-19 pandemic on user experience with online education platforms in China, *Sustainability* 12 (18) (2020), <https://doi.org/10.3390/su12187329>.
- [14] D. Salman, C. Soliman, Insights from online education in the Egyptian higher education, *Int. J. Educ. Manag.* 37 (1) (2022) 135–146, <https://doi.org/10.1108/IJEM-05-2022-0173.->
- [15] M.E. Hassan, A.F. Alzain, S. Kajoak, H. Osman, Prevalence of spinal disorders in Saudi population using conventional radiology: age and gender correlation, *Med. Sci.* 26 (2022), e2195.

- [16] Y. Hu, J. Zhou, B. Gao, Design and analysis of interactive multimedia online physical education platform considering moving object segmentation algorithm, *Adv. Multimed.* 2021 (2021) 1–7, <https://doi.org/10.1155/2021/1220512>.
- [17] A. Baytak, The health students' perception of online education amid the pandemic, *Research in Social Sciences Technology* 7 (2) (2022) 49–65, <https://doi.org/10.46303/ressat.2022.9>.
- [18] S.M. Attardi, D.J. Harmon, M. Barremkala, D.C. Bentley, K.M. Brown, J.F. Dennis, C.J. Ramnaran, An analysis of anatomy education before and during Covid-19: august–December 2020, *Anat. Sci. Educ.* 15 (1) (2022) 5–26, <https://doi.org/10.1002/ase.2152>.
- [19] X. Hong, S. Zhao, Q. Liu, Unusual experience in the COVID-19 pandemic: Young children's readjustment from home to preschool following school closures in different risk regions, *Int. J. Environ. Res. Publ. Health* 19 (24) (2022), 16785, <https://doi.org/10.3390/ijerph192416785>.
- [20] Z. Zhou, S. Graham, T.P. Hsiang, Teaching Chinese characters to first and second graders during the first covid-19 school closure in China: an observational study, *Read. Writ.* (2022) 1–34, <https://doi.org/10.1007/s11145-022-10398-9>.
- [21] A. Tanhan, C. Boyle, B. Taş, Y. Söğüt, C.C. Cashwell, E. Genc, H.T. Karatepe, Using online photovoice and community-based participatory research to understand facilitators and barriers to online distance education during COVID-19, *Dist. Educ.* 44 (1) (2023) 40–65, <https://doi.org/10.1080/01587919.2022.2156320>.
- [22] M. Nusrat, Educational response toward COVID-19 pandemic: perception, problems and prospects; A Bangladeshi context, *European Journal of Education Pedagogy* 2 (5) (2021) 25–32, <https://doi.org/10.24018/ejedu.2021.2.5.163>.
- [23] A. Uzorka, Y.A. Makeri, Academic challenges faced by students in higher education during COVID-19 pandemic, *International Journal of Research Innovation in Social Science* 4 (7) (2020) 421–425, <https://doi.org/10.23887/jpp.v5i41.29703>.
- [24] M. Srinivasan, D. Jishnu, R. Shamala, COVID-19 and online education: digital inequality and other dilemmas of rural students in accessing online education during the pandemic, *World of Media, Journal of Russian Media Journalism Studies* 4 (2021) 34–54, <https://doi.org/10.30547/worldofmedia.4.2021.2>.
- [25] H.A. Patrinos, Learning loss and learning recovery, *Decision* 49 (2) (2022) 183–188, <https://doi.org/10.1007/s40622-022-00317-w>.
- [26] A. Tomy, S. Patel, S.R. Jena, The Impact of Covid-19 Pandemic on Global Education, *Solid State Technology*, 2020, pp. 7944–7954.
- [27] S. Basnet, H.B. Basnet, D.K. Bhattarai, Challenges and opportunities of online education during Covid-19 situation in Nepal, *Rupantaran: A Multidiscip. J.* 5 (2021) 89–99, <https://doi.org/10.3126/rupantaran.v5i01.39867>.
- [28] M. Shakil, B. Khan, A.Z. Ali, S. Javed, A. Mukhtar, M.A. Khan, A. Muazzam, Investigating distorted thinking patterns and psychological distress in students taking online education during COVID-19 outbreak, *Eur. J. Educ. Res.* 98 (98) (2022) 58–69, [10.14689/ejer](https://doi.org/10.14689/ejer).
- [29] D. Ishimaru, H. Adachi, H. Nagahara, S. Shirai, H. Takemura, N. Takemura, M. Ikeda, Characteristics of adaptation in undergraduate university students suddenly exposed to fully online education during the COVID-19 pandemic, *Front. Psychiatr.* 12 (2021), 731137.
- [30] Á. Benito, K. Dogan Yenisey, K. Khanna, M.F. Masis, R.M. Monge, M.A. Tugtan, R. Vig, Changes that should remain in higher education post COVID-19: a mixed-methods analysis of the experiences at three universities, *Higher Learning Research Communications* 11 (4) (2021) 51–75, <https://doi.org/10.5590/10.18870/hlrc.v11i0.1195>.
- [31] Z. Mohamadi Zenouzagh, The effect of professional teaching videos induction and online focused group discussion on the development of teacher competences, *Educ. Res. Pol. Pract.* 21 (3) (2022) 465–488, <https://doi.org/10.1007/s10671-022-09318-z>.
- [32] E. Edelhauser, L. Lupu-Dima, One year of online education in COVID-19 age, a challenge for the Romanian education system, *Int. J. Environ. Res. Publ. Health* 18 (15) (2021) 8129, <https://doi.org/10.3390/ijerph18158129>.
- [33] B. Boruah, Opportunities and challenges of education during COVID-19 pandemic, *Int. J. Health Sci.* (2022) 2872–2878, <https://doi.org/10.53730/ijhs.v6nS1.5285>.
- [34] S.M. González-Betancor, A.J. López-Puig, M.E. Cardenal, Digital inequality at home. The school as compensatory agent, *Computers Education* 168 (2021), 104195, <https://doi.org/10.1016/j.compedu.2021.104195>.
- [35] K.A. Baniomar, The impact of the shift to distance learning on the seven principles of good practices in university education in light of the COVID-19 pandemic, *Kıbrıslı Eğitim Bilimleri Dergisi* 17 (5) (2022) 1533–1548, <https://doi.org/10.18844/cjes.v17i5.7218>.
- [36] A.-M. Dima, G.-M. Meghisan-Toma, Research on implementing education for sustainable development, Paper presented at the Proceedings of the international conference on business excellence 17 (5) (2018) 1533–1548, <https://doi.org/10.18844/cjes.v17i5.7218>.
- [37] C. Păunescu, D. Drăgan, O. Găucă, Examining obligations to society for QS Stars best ranked universities in social responsibility. Management marketing, Challenges for the knowledge society 12 (4) (2017) 551–570, <https://doi.org/10.1515/mmcs-2017-0033>.
- [38] M. Brähler, M. Schultze, Students' innovation in education for sustainable development—a longitudinal study on interdisciplinary vs. Monodisciplinary learning, *Sustainability* 13 (3) (2021) 1322, <https://doi.org/10.3390/su13031322>.
- [39] T. Olushola, U. Haruna, A.S. Mohammed, M. Salisu, Emerging innovations in teaching business education for sustainable development, *European Journal of Business Innovation Research* 10 (6) (2022) 10–17, <https://doi.org/10.37745/ejbir.2013/vol10.n6pp10>.
- [40] M.V. Yurina, Y.V. Lopukhova, G.D. Kuznetsova, Education for sustainable development: new opportunities with the rce network. *Vestnik of Samara State Technical University Psychological, Pedagogical Sciences* 16 (4) (2019) 211–221, <https://doi.org/10.17673/vsgtu-pps.2019.4.14>.
- [41] P.K. Sahu, H. Dalcik, C. Dalcik, M.M. Gupta, V.K. Chattu, S. Umakanthan, Best practices for effective implementation of online teaching and learning in medical and health professions education: during COVID-19 and beyond, *AIMS public health* 9 (2) (2022) 278, doi: [publichealth.2022019](https://doi.org/10.3934/publichealth.2022019).
- [42] L. Vulpe, S. Pribac, Teachers' adaptability to online education during COVID-19, *Journal of Educational Sciences* 22 (2021) 63–78, <https://doi.org/10.35923/JES.2021.2.05>.
- [43] A.V. Agbedahin, Sustainable development, education for sustainable development, and the 2030 Agenda for sustainable development: emergence, efficacy, eminence, and future, *Sustain. Dev.* 27 (4) (2019) 669–680, <https://doi.org/10.1002/sd.1931>.
- [44] S. Maity, T.N. Sahu, N. Sen, COVID-19 and digital primary education: impact and strategies for sustainable development, *Journal of Development Policy Practice* 7 (1) (2022) 10–30, <https://doi.org/10.1177/24551333211049630>.
- [45] I. Kudeikina, I.J. Mihailovs, J. Zivarts, Academic integrity in education in the context of sustainable development of society, *Eur. J. Sustain. Dev.* 11 (2) (2022), <https://doi.org/10.14207/ejsd.2022.v11n2p83>, 83–83.
- [46] D. Daw-as, S.M.C. Magat, Lived experiences of physical education instructors in facilitating distance learning education, *International Journal of Physical Education, Fitness and Sports* 11 (2022) 12–23, <https://doi.org/10.34256/ijpefs2242>.
- [47] Y. Yan, L. Vyas, A.M. Wu, S. Rawat, Effective online education under COVID-19: perspectives from teachers and students, *J. Publ. Aff. Educ.* 28 (4) (2022) 422–439, <https://doi.org/10.1080/15236803.2022.2110749>.
- [48] R. Lin, J. Yang, F. Jiang, J. Li, Does teacher's data literacy and digital teaching competence influence empowering students in the classroom? Evidence from China, *Educ. Inf. Technol.* 28 (3) (2023) 2845–2867, <https://doi.org/10.1007/s10639-022-11274-3>.
- [49] B.L. Moorhouse, Beginning teaching during COVID-19: newly qualified Hong Kong teachers' preparedness for online teaching, *Educ. Stud.* (2021) 1–17, <https://doi.org/10.1080/03055698.2021.1964939>.
- [50] X. Zhang, S. Li, S. Wang, J. Xu, Influence of job environment on the online teaching anxiety of college teachers in the online teaching context: the mediating role of subjective well-being, *Front. Public Health* 10 (2022) 3867, <https://doi.org/10.3389/fpubh.2022.978094>.
- [51] S.M. Tsegay, M.A. Ashraf, S. Perveen, M.Z. Zegergish, Online teaching during COVID-19 pandemic: teachers' experiences from a Chinese university, *Sustainability* 14 (1) (2022) 568, <https://doi.org/10.3390/su14010568>.
- [52] J. Zhang, S. Yu, Reconceptualising digital pedagogy during the COVID-19 pandemic: a qualitative inquiry into distance teaching in China, *Innovat. Educ. Teach. Int.* 60 (2) (2023) 174–184, <https://doi.org/10.1080/14703297.2021.2000473>.
- [53] H. Cook, T. Apps, K. Beckman, S. Bennett, Digital competence for emergency remote teaching in higher education: understanding the present and anticipating the future, *Educ. Technol. Res. Dev.* 71 (1) (2023) 7–32, <https://doi.org/10.1007/s11423-023-10194-4>.
- [54] T. Fütterer, E. Hoch, A. Lachner, K. Scheiter, K. Stürmer, High-quality digital distance teaching during COVID-19 school closures: does familiarity with technology matter? *Computers Education* 199 (2023), 104788 <https://doi.org/10.1016/j.compedu.2023.104788>.
- [55] J. Hulland, Use of partial least squares (PLS) in strategic management research: a review of four recent studies, *Strat. Manag. J.* 20 (2) (1999) 195–204, [https://doi.org/10.1002/\(sici\)1097-0266\(199902\)20:2%3C195::aid-smj13%3E3.0.co;2-7](https://doi.org/10.1002/(sici)1097-0266(199902)20:2%3C195::aid-smj13%3E3.0.co;2-7).

- [56] Ş. Altay, G.G. İnan, AN empirical study of technology acceptance in higher education during COVID-19 pandemic, *Pazarlama ve Pazarlama Araştırmaları Dergisi* 15 (2) (2022) 481–504, <https://doi.org/10.15659/ppad.15.2.997751>.
- [57] H. Wang, J. Wu, M. Muhedaner, S. Maihemuti, College students online education evaluation through SWOT analysis during covid-19, *IEEE Access* 10 (2022) 88371–88385, <https://doi.org/10.1109/ACCESS.2022.3198082>.
- [58] Y.M. Tang, P.C. Chen, K.M. Law, C.-H. Wu, Y.-y. Lau, J. Guan, G.T. Ho, Comparative analysis of Student's live online learning readiness during the coronavirus (COVID-19) pandemic in the higher education sector, *Computers education* 168 (2021), 104211, <https://doi.org/10.1016/j.compedu.2021.104211>.
- [59] T. Toader, M. Safta, C. Titirişca, B. Firtescu, Effects of digitalisation on higher education in a sustainable development framework—online learning challenges during the COVID-19 pandemic, *Sustainability* 13 (11) (2021) 6444, <https://doi.org/10.3390/su13116444>.
- [60] M. Li, Y. Su, Evaluation of online teaching quality of basic education based on artificial intelligence, *International Journal of Emerging Technologies in Learning* 15 (16) (2020) 147–161, <https://doi.org/10.3991/ijet.v15i16.15937>.
- [61] J.F. Hair, C.M. Ringle, M. Sarstedt, PLS-SEM: indeed a silver bullet, *J. Market. Theor. Pract.* 19 (2) (2011) 139–152, <https://doi.org/10.2753/MTP1069-6679190202>.
- [62] J. Henseler, C.M. Ringle, M. Sarstedt, Testing measurement invariance of composites using partial least squares, *Int. Market. Rev.* (2016), <https://doi.org/10.1108/IMR-09-2014-0304>.
- [63] J.F. Hair Jr., G.T.M. Hult, C.M. Ringle, M. Sarstedt, N.P. Danks, S. Ray, M. Sarstedt, Evaluation of reflective measurement models, *Partial Least Squares Structural Equation Modeling Using R: Work* (2021) 75–90, https://doi.org/10.1007/978-3-030-80519-7_4.
- [64] A. Napier, E. Huttner-Loan, J. Reich, Evaluating learning transfer from MOOCs to workplaces: a case study from teacher education and launching innovation in schools. *RIED, Revista Iberoamericana de Educación a Distancia* 23 (2) (2020) 45–64, <https://doi.org/10.5944/ried.23.2.26377>.
- [65] F. Malenya, Provision of basic education in the context of the COVID-19 pandemic in Kenya, *Journal of International Cooperation in Education* 24 (2) (2021) 27–44.
- [66] Z. Armoed, The COVID-19 pandemic: online teaching and learning at higher education institutes, Paper presented at the IOP Conference Series: Earth and Environmental Science 654 (1) (2021), 012026, <https://doi.org/10.1088/1755-1315/654/1/012026>.