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Impact of 3D learning resources on learning resilience: mediating roles of positive emotion and cognitive load

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Three-dimensional (3D) learning resources are increasingly being integrated into classrooms and becoming important teaching tools. Learning resilience is a crucial factor affecting learning outcomes. However, the impact of 3D learning resources on learning resilience has not been received sufficient academic attention. This study constructs a structural equation model based on the broaden-and-build theory and cognitive load theory to examine the impact of 3D learning resources on learning resilience. To examine the mechanism of this impact, including the mediating roles of positive emotion and cognitive load, we collected 963 valid questionnaires from college students in Shandong Province, China. The results indicate that 3D learning resources are significantly positively correlated with positive emotion and learning resilience and negatively correlated with cognitive load. Moreover, cognitive load is negatively correlated with learning resilience. Positive emotion and cognitive load serve as mediators in the relationship between 3D learning resources and learning resilience. Therefore, developing high-quality 3D learning resources, cultivating positive emotions among students and reducing cognitive load can enhance college students' learning resilience and mitigate academic risks.

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Introduction

Information technologies play a pivotal role in adapting to the demands of modern education, with the potential to enhance accessibility, individualisation, and the overall active nature of the learning process (Sholihin et al. 2020). Three-dimensional (3D) learning resources, which originate from the computer game industry, can facilitate new levels of learner-learner and learner-computer interactions (Yang et al. 2023). The term '3D learning resources' refers to educational materials that leverage 3D technology to enhance the learning experience. These resources encompass a diverse range of applications, such as 3D video and animation, virtual reality (VR) and augmented reality (AR), designed to facilitate an immersive and engaging learning environment. The integration of 3D elements aims to provide learners with a spatial understanding of subjects, fostering a dynamic and interactive space for exploration and knowledge acquisition. These resources transcend traditional two-dimensional learning materials, offering students the opportunity to interact with and manipulate 3D models and ultimately contributing to a deeper comprehension of complex concepts. Numerous studies have reported that the use of 3D learning resources, such as 3D web-based, computer-based, and mobile-based 3D models, can provide students with clearer understanding and knowledge (Khayruddeen et al. 2019). Moreover, 3D learning resources offer simulations for practicing skills (Fromm et al. 2021), demonstrating their benefit in representing concepts that are typically beyond the reach of the human senses.

Beyond the cognitive benefits, the immersive and interactive nature of 3D learning resources can also impact students' emotional and psychological states. Learners utilising 3D learning resources in classes exert greater efforts to overcome adverse factors (Mou 2024), indicating a potential link between these resources and students' resilience in the face of learning challenges. In the field of psychology, resilience is defined as the ability of individuals to maintain positive adaptation in the face of significant adversity (Denckla et al. 2020). It helps individuals recover from setbacks and maintain optimism in challenging situations (Carver and Scheier, 2001). Resilience not only aids in overcoming life challenges but also plays a critical role in learning by enabling students to quickly regain equilibrium when faced with learning adversity (Ruospo et al. 2023). Thus, a high level of resilience can increase the likelihood of achieving long-term success (Li et al. 2024). Given the benefits and potential link of 3D learning resources and its potential relevance to learning resilience in higher education, we propose the following research questions:

RQ 1: Does the widespread use of 3D learning resources have an impact on students' learning resilience?

RQ 2: How do 3D learning resources affect students' learning resilience?

Previous studies on higher education have primarily focused on the advantages of employing 3D learning environments and models as teaching tools (Murillo-Zamorano et al. 2021). However, there is limited research on how 3D learning resources affect students' behaviour in terms of learning resilience and the underlying mechanisms promoting students' ability to learn with resilience (Chen, 2020). To address this gap, we incorporate the broaden-and-build theory and cognitive load theory to comprehensively examine the impact of 3D learning resources on college students' learning resilience. By constructing a theoretical model linking 3D learning resources, positive emotion, cognitive load, and learning resilience, this study explores three paths for 3D learning resources to affect learning resilience, and evaluates the effects of each path.

Compared with previous studies, the theoretical contribution of this study lies in constructing a theoretical model to evaluate the influence of 3D learning resources on learning resilience through three paths. The analysis results based on this model highlight both the similarities with existing studies, and the novel insights that advance the current knowledge system. This study provides essential reference and guidance for college administrators aiming to enhance teaching quality and effectively promote students' learning resilience effectively.

Theoretical background and research hypotheses

Learning resilience. Resilience was originally a physics concept. In the 1970s and 1980s, it became a new direction in the study of psychological development and individual growth. In psychology, Werner and Smith (1982) lucidated that resilience is an ability and dynamic process enabling individuals to adapt well to difficulties and adversities. Building on research into psychological resilience, scholars began to concentrate on students' learning, leading Martin et al. (2013) to propose the concept of learning resilience. Learning resilience is the response of psychological resilience in learning psychology, which refers to the ability of learners to successfully respond and adapt well when faced with learning difficulties or challenges (Martin et al. 2013).

College students' learning resilience is shaped by multiple factors, including their individual cognitive processes, familial environment, educational institution and societal influences (Table 1). An individual's emotions are a critical factor that affects learning resilience. Martin et al. (2013) affirmed that individuals can enhance their learning through positive (optimistic and constructive) emotions. Conversely, those who approach learning with negative (pessimistic and disappointing) emotions may encounter barriers. Guo and Li (2022) explored the psychological resilience of Chinese learners of English as a foreign language, highlighting that emotional aspects within positive psychology (such as motivation, boredom, enjoyment, well-being, engagement and the flow experience) play a crucial role promoting psychological resilience. Additionally, various external factors contribute significantly to cultivating students' learning resilience. Within families, the warmth, emotional understanding, parenting style, maternal protective instincts and emotional support are important influences on individual's psychological resilience (Radhamani and Kalaivani 2021). Parents' regular involvement in students' everyday lives, combined with less frequent interference in their academic pursuits, can effectively foster learning resilience (Cui et al. 2024). At school, teachers' strong self-efficacy, high academic expectations and encouragement also play active roles in cultivating students' learning resilience (Takizawa et al. 2024).

Currently, existing studies on student learning resilience predominantly focus on measuring learning resilience, analysing its current state formulating strategies, studying predictive model and investigating factors that influence learning resilience. With the increasing usage of information technology in education, 3D learning resources have emerged as essential tools and methodologies in higher education teaching. Nevertheless, the existing research has not comprehensively elucidated the impact mechanisms of 3D learning resources on the learning resilience of college students from an empirical perspective. Through an empirical exploration of the factors affecting college students' learning resilience, this study aims to unveil the reasons behind the current phenomenon of 'low persistence' among college students, which can help address the problem of high dropout and failure rates among college students. Moreover, this study will explore the impact mechanisms of 3D learning resources on the learning resilience of college students, thereby contributing to the theoretical foundation of research on the influencing mechanisms of learning resilience among college students.

Table 1 Influencing factors of learning resilience.

Factors	Main contents	Methods	Main conclusions	References
Social support	Confirmed each item on perceived social support e.g., peers, families, and teachers on learning resilience based on online learning.	Structural equation modelling	Perceived social support can encourage students to remain persistent in facing all obstacles and difficulties while carrying out the learning process.	Permatasari et al. (2021)
Teacher support	Investigated the internal structure of student learning resilience in language learning	Structural equation modelling	Teacher support can positively influence students' learning resilience in English learning.	Duan et al. (2024)
Personality	Identified undergraduate medical students' level of resilience and its relationships to personality.	Cross-sectional study	Personality traits may predict resilience among medical students.	Findyartini et al. (2021)
Family socio-economic status (SES)	Explored the mediating effects of resilience and future orientation on the relationship between SES and learning engagement.	Structural equation modelling	SES is significantly and positively correlated with resilience.	Chen et al. (2021)
Family communication patterns	Examined the relationship between family communication patterns and learning resilience.	Structural equation modelling	Family communications especially the relationship between parents with children are important for learning resilience.	Jowkar et al. (2011)
Grade Point Average (GPA)	Investigated the heterogeneity of learning resilience among nursing students and its associated influencing factors.	Latent profile analysis	GPA significantly influences the learning resilience of nursing students.	Tan et al. (2024)
Characteristics of classes	Examined the possible constituents of students' language learning demotivation, and how they interact with the resilience.	Structural equation modelling	Classroom environment, classroom learning materials and characteristics of classes can stimulate students to be motivated and develop learning resilience.	Pathan et al. (2021)
Collaborative learning	Determined whether engaging in collaborative learning influences persistence	Structural equation modelling	Learning collaboratively leads to greater levels of positive peer interactions, which in turn is associated with higher learning resilience.	Loes et al. (2017)

3D learning resources. Emerging technologies, such as 3D imaging, are reshaping people's lives. 3D films and games have become seamlessly integrated into the daily lives of the younger generation. Concurrently, the educational sector is actively exploring the integration of emerging technologies to enhance teaching levels and effectiveness, and 3D technology is being widely applied in educational settings across various disciplines, including engineering design graphics (Henstrom et al. 2024), engineering mechanics (Fortuna et al. 2023), chemistry (Amirbekova et al. 2024) and dentistry (Ho et al. 2022).

3D learning resources refer to educational materials that leverage 3D representations, such as 3D video and animation, VR and AR, to convey information to learners. They also affect interactions in online problem-based learning. Students can work together in virtual environments, share ideas, discuss concepts and solve problems collaboratively (Omale 2010). By presenting information in a visually appealing and interactive format, 3D learning resources not only immerse students in a captivating learning experience but also provide a vibrant and expressive means for presenting teaching content (Yao 2024). The application of 3D learning resources can enhance the visualisation and comprehensibility levels of classroom teaching. For instance, a 3D model can effectively illustrate the internal anatomical components of the human body in anatomy curricula (Duarte et al. 2020). Additionally, 3D learning resources have been identified as catalysts for collaborative learning, fostering student-faculty interactions (Zarandi et al. 2022). In turn, this encourages heightened engagement among students, consequently boosting learning resilience (Lacka et al. 2021).

From these arguments, the following hypotheses were formulated:

Hypothesis 1: 3D learning resources positively influence learning resilience.

Hypothesis 2: 3D learning resources positively influence positive emotion.

Broaden-and-build theory. The 'broaden-and-build' theory was proposed by psychologist Fredrickson in 1998 (Fredrickson 1998). This theory posits that positive emotions, such as joy, gratitude and love, broaden an individual's momentary thought-action repertoires. Unlike negative emotions, which narrow one's focus towards specific actions, positive emotions prompt individuals to consider a wider array of potential actions and foster cognitive flexibility. Moreover, the theory suggests that the broadening effect of positive emotions contributes to the building of enduring personal resources, including increased resilience, coping mechanisms, and overall psychological well-being (Fredrickson 2001). In this sense, this theory can explain the influence of 3D learning resources on students' learning resilience from the perspective of positive effects.

Resilience is associated with positive emotions (Israelashvili 2021). Students with a higher prevalence of positive emotions tend to derive greater enjoyment from campus life. These students exhibit a proactive approach to learning by formulating study plans, adjusting their strategies promptly when faced with setbacks and adapting to an ever-changing academic landscape. Furthermore, in response to challenges encountered in their academic journey, these students reflect on areas of maladaptation, aiming to minimise

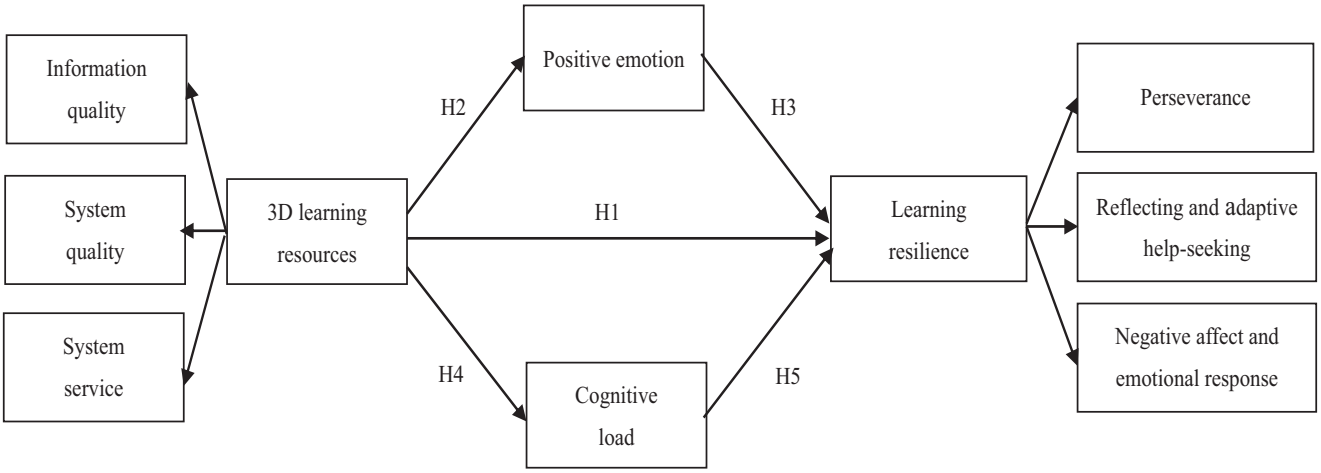

Fig. 1 Theoretical model.

deviations in behaviour (Denovan and Macaskill 2017). In essence, students with positive emotions can better confront learning setbacks and hardships, thereby embodying a sense of learning resilience, compared with those having negative emotions. Shin and Kim (2017) confirmed that demotivation negatively affects resilience in South Korean elementary school students' English learning. Gilchrist et al. (2023) validated that positive emotions result in a cascade of beneficial outcomes among adolescents, including increased resilience.

From these arguments, the following hypothesis was formulated:

Hypothesis 3: Positive emotion positively influences learning resilience.

Cognitive load theory. The 'cognitive load' theory was proposed by educational psychologist John Sweller in the late 1980s (Sweller 1988). This theory revolves around the idea that the capacity of working memory is limited., When the cognitive load imposed by intellectual activities on working memory exceeds its maximum capacity, an individual's learning efficiency will decrease (Sweller et al. 1998).

The cognitive load theory identifies three types of cognitive load: the intrinsic cognitive load, which is determined by the nature of the task, the individual's skill level and the interaction between them; the extraneous cognitive load, which is influenced by the task's presentation format; and the germane cognitive load, which is related to schema formation and application (Van Merrienboer and Sweller, 2005). If the cognitive load exceeds the capacity of working memory, then it can lead to cognitive overload, resulting in learning difficulties, decreased efficiency (Dutt and Ahuja, 2024), and reduced learning resilience. In this sense, this theory can explain the influence of 3D learning resources on students' learning resilience from the perspective of negative effects.

Well-designed 3D learning resources can reduce extraneous cognitive load by providing more concrete and intuitive representations of concepts (Dan and Reiner 2018). When learners can interact with 3D objects or environments, it may lead to better comprehension and retention of information, as it aligns with the natural ways our brains perceive and process the physical world (Papanastasiou et al. 2019).

From the above arguments, the following hypotheses were formulated:

Hypothesis 4: 3D learning resources negatively influence cognitive load.

Hypothesis 5: Cognitive load negatively influences learning resilience.

Figure 1 shows the theoretical model employed in this study.

Methodology

The empirical research was conducted in universities in Shandong Province, China. In September 2022, under the guidance of the Shandong Provincial Education Department, all 153 universities in Shandong began implementing reforms to improve the quality of university talent cultivation through classroom teaching reforms. These reforms aim to improve the quality of classroom teaching, stimulate students' enthusiasm for active learning and enhance the quality of talent cultivation. As part of these efforts, many universities have adopted 3D digital resources to improve teaching effects. This study focuses on classrooms using 3D digital resources as the analytical objects of empirical research.

Scales. This study used a seven-point Likert scale to collect data. In this scale, '1' denotes strong disagreement with a given statement, while '7' indicates strong agreement with the statement. Following the theoretical model, we designed 35 measurement items for eight variables. All the items were designed with reference to literature. Specifically, items for the five variables, namely, information quality, system quality, service quality, positive emotion and cognitive load, were all designed on the basis of previous studies, while items for the three variables, namely, perseverance, reflective and adaptive help-seeking and negative affect and emotional response were derived from the Academic Resilience Scale (ARS-30). Notably, we designed the two variables of 3D learning resources and learning resilience as second-order factors. 3D learning resources are measured with three first-order factors: information quality, system quality and service quality. Learning resilience is represented by three first-order factors: reflective and adaptive help-seeking, perseverance and negative affect and emotional response. Table 2 shows the details of all the items.

Data collection. In the present study, the title of the questionnaire is 3D Learning Resources Questionnaire. The data collection included two stages: a pilot survey and a formal survey. In the pilot survey stage, we distributed the questionnaire to five teachers and 20 students in the 3D digital resource classroom to verify the clarity and appropriateness of the survey content. The results confirmed that all the items were easy to understand and

Table 2 Specific items in the investigation.

Variables	Items		References
3D learning resources	Information quality	The content provided by the 3D learning resources is complete. The content provided by the 3D learning resources is easy to comprehend. The content of the course materials provided by the 3D learning resources is timely. The course materials provided by the 3D learning resources are well represented with text and graphics. The content of the course materials provided by the 3D learning resources is relevant to the topic of the course materials.	Chiu et al. (2007)
	System quality	The 3D learning resources are easy to use. The 3D learning resources are user-friendly. The 3D learning resources are stable. The response time of the 3D learning resources is acceptable. The 3D learning resources have clear navigational tools and guidelines for assisting use.	Lin & Wang (2012)
	Service quality	The 3D learning resources help me get problem solutions. The information provided by the 3D learning resources is reliable. The 3D learning resources provide services from students' perspective.	Wang & Chiu (2011)
Positive emotion	Using the 3D learning resources to study is a good idea. Using the 3D learning resources to study is a wise idea. I like the idea of using the 3D learning resources. Using the 3D learning resources is pleasant.		Davis et al. (1989)
Cognitive load	I felt that the content of the 3D learning resources was challenging for me. It was hard for me to predict the answers in the 3D learning resources. I lost my attention when observing the animation in the 3D learning resources. I had to focus really hard to adapt to the way the 3D learning resources transitioned.		Hong et al. (2017)
Learning resilience	Perseverance	I would study harder when using the 3D learning resources. I would keep trying when using the 3D learning resources. I would use the feedback in the 3D learning resources to improve my learning. I would try to think of new solutions through 3D learning resources.	Cassidy (2016)
	Reflecting and adaptive help-seeking	I would try to think more about my strengths and weaknesses to help me learn better when using the 3D learning resources. I would give myself encouragement when using the 3D learning resources. I would try different ways to study when using the 3D learning resources. I would seek help from my tutors when using the 3D learning resources. I would start to monitor and evaluate my achievements and effort when using the 3D learning resources. I would use my past successes to help motivate myself when using the 3D learning resources.	Cassidy (2016)
	Negative affect and emotional response	I would feel like everything was ruined and was going wrong when using the 3D learning resources. I would probably get depressed when using the 3D learning resources. I would be very disappointed when using the 3D learning resources. I would stop myself from panicking when using the 3D learning resources.	Cassidy (2016)

Table 3 Descriptive statistics of the respondents' characteristics ($N = 963$).

Demographics	Category	Frequency	Percentage (%)
Gender	Male	477	49.53
	Female	486	50.47
Age	≤18	314	32.61
	19	295	30.63
	20	288	29.91
	≥21	66	6.85
Academic year	Freshman	356	36.97
	Sophomore	274	28.45
	Junior	278	28.87
	Senior	55	5.71
Speciality type	Management	302	31.36
	Economics	243	25.23
	Art	156	16.20
	Philology	105	10.91
	History	87	9.03
	Others	70	7.27

that the survey contents were reasonable and complete. In the formal survey stage, the convenience sampling method was employed to collect the data. We relied on the Academic Affairs Office of one of the universities in Shandong Province to contact the Academic Affairs Offices of other universities in Shandong Province to determine which universities were utilising 3D digital resources in classrooms. Upon identifying the objects of the investigation, we asked the teachers whether they could help us complete this academic investigation. When the teachers agreed, we sent the students the link to the online questionnaire. The survey was completely anonymous, and students volunteered to participate by accessing the questionnaire through a link on their mobile phones. The survey period was from 18 October 2023 to 6 December 2023. In total, 1,253 questionnaires were obtained during the formal survey stage. After screening, 963 samples were found to be valid. According to the research of Raykov and Marcoulides (2006), the model is stable in the analysis process only when the sample size is more than 10 times of the estimated parameters of the model. In the current study, with 81 estimated parameters in the model, the effective sample size ensures the model's statistical power.

Respondents' characteristics. Detailed descriptive statistics of respondents' characteristics are shown in Table 3. In addition, Table 4 exhibits the information of all items in this survey. We conducted Kolmogorov–Smirnov (K–S) tests to examine the normality in all items by using SPSS 18.0 software. The K–S Z scores indicate that there is a significant difference between the distribution of every item and the normal distribution. From Table 4, we can get a general understanding of the response to each item.

Results

Reliability and validity tests. A factor analysis was conducted using SPSS 18.0 software. The results affirm that the KMO value is 0.90, suggesting that the data met the basic conditions of the reliability and validity tests (Zhu et al. 2019). Additionally, the results indicate that the factor loading of NA4 is low (< 0.7) and that the other factor loadings reach a threshold of 0.7 (Table 5). Thus, we removed the variable NA4 prior to the reliability and validity analyses (Dash and Paul, 2021).

In the reliability analysis, to measure the results, Cronbach's α and composite reliability (CR) were used. Table 5 shows that the Cronbach's α and CR values of each variable are more than 0.7, meaning that this scale has good reliability (Afthanorhan et al. 2020). In the validity analysis, the average variance extracted (AVE) was used to display the convergent validity. The results validate that the AVE values of all the variables are more than 0.5 (Table 5), which meets the basic requirements (Amado et al. 2023). Moreover, in the analysis results exhibited in Table 6, the square root value of each variable AVE (the values on the main diagonal) exceeds the correlations between the variable and other variables, indicating that the scale has good discriminant validity (Rappaport et al. 2020). Good convergent validity and discriminative validity indicate that the overall validity of the scale is good.

Homogeneity test. In the present research, there are differences in gender, grade and specialty among students. Their knowledge and experience may lead to different understandings of all items on the scale. Therefore, before hypothesis testing, we conducted a homogeneity test to examine whether the students in this survey had equivalent understanding of the items. After the analysis of variance, the F-test results indicated that gender, grade and major do not have significant differences in the understanding of students. In other words, the personal attributes of the respondents did not affect the analysis results.

Common method bias test. In this study, the common method biases were evaluated by Harman's single factor test. The results verified that the explanatory proportion of the largest variance factor was 34.16%, which indicated that there were no common method biases (Zhu et al. 2019). Therefore, common method bias was not a critical issue in this study.

Hypothesis test. We used Lisrel 8.7 software for structural equation modelling analysis. The analysis results (Table 7) affirm that we have a well-fitting model. All fitting indicators meet the basic requirements, indicating that the hypothesis test results obtained based on this model are reliable (Esfandyari et al. 2023). Figure 2 illustrates the results of the hypothesis test, showing that all path coefficients in the model are significant. In other words, all five hypotheses of this study are supported.

Mediation effect test. The hypothesis test results confirmed that positive emotion and cognitive load play a mediating role in the process of 3D learning resources affecting learning resilience. To test the mediation effect of these two variables, we used Mplus 7.0 software and a bootstrapping method to test the mediation role. We set up 95% bias-corrected confidence intervals and the repeated 3000 bootstrap samples. The results confirm that the mediation effect confidence intervals of positive emotion and cognitive load are [0.067, 0.121] and [0.042, 0.090], respectively. These two confidence intervals do not include zero. Therefore, both positive emotion and cognitive load play a significant mediation role. Because H1 is supported in this study, we conclude that 3D learning resources can either directly affect students' learning resilience or indirectly influence learning resilience through positive emotion and cognitive load, respectively.

Conclusions

This study explored the relationships among 3D learning resources, positive emotion, cognitive load, and college students' learning resilience. The findings support the hypothesis that 3D learning resources and positive emotion positively influence the learning resilience of college students, while cognitive load negatively affects their learning resilience. Specifically, positive emotion plays a significant mediating role in the impact of 3D learning resources on

Table 4 Descriptive statistics of all measurement items.

Variables	Dimension	Items	Mean	Standard deviation	Skewness	Kurtosis
Visual learning resources	Information quality	IQ1	5.91	1.15	−1.52	3.08
		IQ2	5.93	1.09	−1.43	3.04
		IQ3	5.92	1.08	−1.45	3.28
		IQ4	5.95	1.04	−1.49	3.65
		IQ5	5.97	1.03	−1.56	4.15
	System quality	SYQ1	5.94	1.04	−1.52	3.75
		SYQ2	5.96	1.04	−1.52	3.76
		SYQ3	5.92	1.07	−1.49	3.57
		SYQ4	5.88	1.10	−1.41	2.94
		SYQ5	5.90	1.09	−1.43	3.13
	Service quality	SEQ1	5.89	1.07	−1.41	3.20
		SEQ2	5.95	1.02	−1.37	3.14
		SEQ3	5.89	1.09	−1.41	3.14
Positive emotion	-	PE1	5.89	1.11	−1.48	3.21
		PE2	5.89	1.10	−1.47	3.28
		PE3	5.87	1.13	−1.44	3.02
		PE4	5.84	1.15	−1.38	2.65
Cognitive load	-	CL1	4.55	1.89	−0.34	−1.08
		CL2	4.53	1.89	−0.35	−1.08
		CL3	4.22	2.00	−0.13	−1.31
		CL4	4.62	1.87	−0.40	−1.02
Learning resilience	Perseverance	PER1	5.77	1.16	−1.27	2.27
		PER2	5.81	1.10	−1.29	2.59
		PER3	5.85	1.09	−1.30	2.62
		PER4	5.82	1.10	−1.13	2.00
	Reflecting and adaptive help-seeking	RA1	5.85	1.07	−1.28	2.65
		RA2	5.82	1.10	−1.25	2.43
		RA3	5.82	1.10	−1.24	2.31
		RA4	5.63	1.24	−1.07	1.40
		RA5	5.80	1.11	−1.26	2.50
		RA6	5.71	1.22	−1.42	2.78
	Negative affect and emotional response	NA1	3.90	2.10	0.03	−1.47
		NA2	3.97	2.06	0.01	−1.42
		NA3	3.88	2.09	0.10	−1.46
		NA4	4.89	1.79	−0.73	−0.50

VLR Visual learning resources, *PE* Positive emotion, *CL* Cognitive load, *LR* Learning resilience, *IQ* Information quality, *SYQ* System quality, *SEQ* Service quality, *PER* Perseverance, *RA* Reflecting and adaptive help-seeking, *NA* Negative affect and emotional response.

the learning resilience of college students, and the mediating effect of cognitive load is also statistically significant. Our research provided the following interesting insights.

First, 3D learning resources positively influence learning resilience. That is, H1 in this study was supported ($\beta = 0.25$, $p < 0.001$). This finding is like the perspectives of existing studies (Lacka et al. 2021; Jung and Lee, 2018). It indicates a positive correlation between 3D learning resources and college students' learning resilience. This conclusion can be employed as a supplement to the studies on the application of 3D resources in university classrooms, which indicates the positive effect of 3D learning resources on students. We believe that the characteristics of 3D learning resources play a notable role in teaching. Compared with other learning resources, 3D learning resources assist students in gaining a more intuitive understanding of abstract concepts and complex knowledge. Moreover, 3D learning resources make the classroom more dynamic and engaging, capturing students' attention and enhancing the attractiveness and enjoyment of learning. These resources can also create interactive learning environments that encourage active participation. The self-efficacy, perceived usefulness, and instructional presence instilled by 3D learning resources stimulate students' learning motivation and facilitate increased learning engagement, thereby influencing students' learning resilience. This conclusion emphasises the practical effect of 3D learning resources and provides empirical support for their widespread adoption.

Second, positive emotion plays a mediating role in the influence of 3D learning resources on the learning resilience of college students. That is, 3D learning resources not only directly impact learning resilience but also indirectly affect it through the mediating function of positive emotion. This conclusion indicates that both H2 ($\beta = 0.89$, $p < 0.001$) and H3 ($\beta = 0.68$, $p < 0.001$) were supported in this study. These results extend the broaden-and-build theory from psychology to the field of education, further validating the notion that positive emotions enhance the ability to cope with adversity. This finding is consistent with various existing research conclusions (Tugade et al. 2004; Zautra et al. 2005). Psychological resilience and positive emotion may not be two independent psychological resources; rather, positive emotion forms an integral component of psychological resilience, serving as a useful resource for managing diverse stressors. Moreover, positive emotion may be a distinctive characteristic of individuals with high psychological resilience, gresulting in a heightened experience of positive emotions and greater proficiency in finding positive meaning in adverse circumstances. Positive emotions can also help individuals effectively regulate negative emotions when facing pressure, acting as a valuable resource for resilient coping when faced with pain and pressure. In the current study, the concept of learning resilience, regarded as a subtype of psychological resilience, also lends support to this hypothesis.

Third, cognitive load functions as a mediating factor. The findings demonstrate that cognitive load mediates the impact of

Table 5 Statistical results of some indicators.

Variables	Dimension	Items	Loadings	AVE	CR	Cronbach α
Visual learning resources	Information quality	IQ1	0.89	0.82	0.96	0.97
		IQ2	0.91			
		IQ3	0.91			
		IQ4	0.92			
		IQ5	0.91			
	System quality	SYQ1	0.92	0.83	0.96	0.97
		SYQ2	0.93			
		SYQ3	0.92			
		SYQ4	0.88			
		SYQ5	0.91			
	Service quality	SEQ1	0.89	0.81	0.93	0.96
		SEQ2	0.92			
		SEQ3	0.89			
Positive emotion	-	PE1	0.84	0.68	0.90	0.97
		PE2	0.83			
		PE3	0.81			
		PE4	0.82			
Cognitive load	-	CL1	0.82	0.69	0.90	0.94
		CL2	0.84			
		CL3	0.88			
		CL4	0.79			
Learning resilience	Perseverance	PER1	0.85	0.80	0.94	0.97
		PER2	0.90			
		PER3	0.92			
		PER4	0.91			
	Reflecting and adaptive help-seeking	RA1	0.93	0.77	0.95	0.97
		RA2	0.93			
		RA3	0.91			
		RA4	0.80			
		RA5	0.90			
		RA6	0.79			
	Negative affect and emotional response	NA1	0.89	0.81	0.93	0.98
		NA2	0.90			
		NA3	0.91			
		NA4	0.58			

VLR Visual learning resources, *PE* Positive emotion, *CL* Cognitive load, *LR* Learning resilience *IQ* Information quality, *SYQ* System quality, *SEQ* Service quality, *PER* Perseverance, *RA* Reflecting and adaptive help-seeking, *NA* Negative affect and emotional response.

Table 6 Statistical results of discriminant validity.

Factors	IQ	SYQ	SEQ	PE	CL	PER	RA	NA
IQ	0.91							
SYQ	0.87	0.91						
SEQ	0.85	0.87	0.9					
PE	0.76	0.76	0.78	0.82				
CL	−0.14	−0.15	−0.15	−0.15	−0.83			
PER	0.76	0.77	0.79	0.79	−0.19	0.89		
RA	0.77	0.78	0.79	0.78	−0.20	0.81	0.88	
NA	0.02	0.02	0.02	0.01	−0.75	0.05	0.07	0.9

PE Positive emotion, *CL* Cognitive load, *IQ* Information quality, *SYQ* System quality, *SEQ* Service quality, *PER* Perseverance, RA Reflecting and adaptive help-seeking, *NA* Negative affect and emotional response.

Table 7 Fitting indices and evaluation criteria of research model.

Fitting indices		Absolutely indices			Parsimony indices		Incremental indices		
	χ^2/df	*GFI*	*AGFI*	*RMSEA*	*PNFI*	*PGFI*	*CFI*	*NFI*	*IFI*
Values of fitting indices	2.931	0.92	0.89	0.075	0.83	0.68	0.99	0.99	0.99
Evaluation criteria values (Dash and Paul, 2021)	<5	>0.9	>0.8	<0.08	>0.5	>0.5	>0.9	>0.9	>0.9

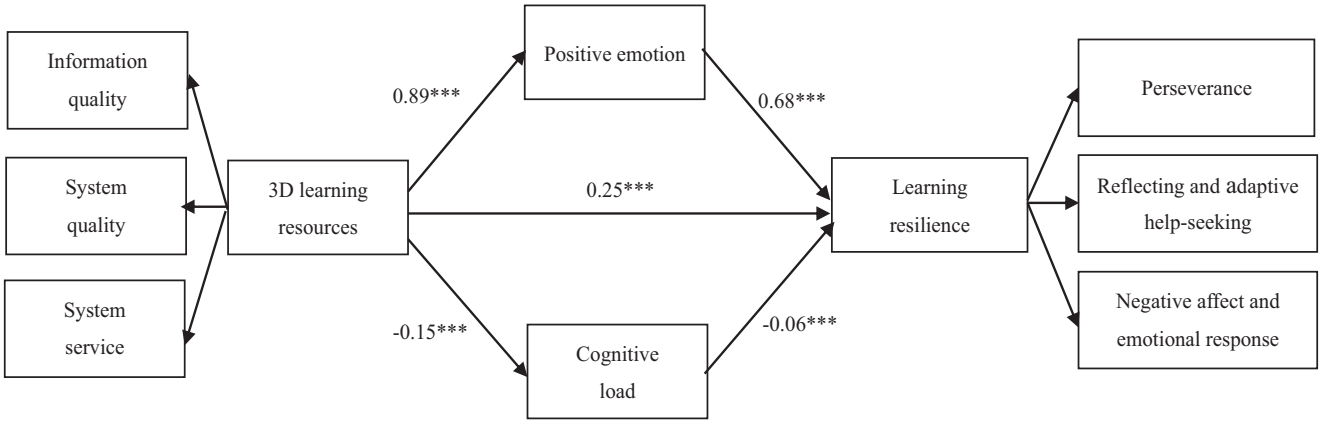

Fig. 2 Standardized path coefficient.

3D learning resources on learning resilience. In other words, 3D teaching resources can both directly influence learning resilience and indirectly affect it through the mediating role of cognitive load, which has not been addressed by previous studies on learning resilience. Cognitive load exhibits a negative correlation with both 3D learning resources and learning resilience. This conclusion indicates that both H4 ($\beta = -0.15$, $p < 0.001$) and H5 ($\beta = -0.06$, $p < 0.001$) were supported in this study. We believe that the main reasons for this conclusion are as follows. As students perceive a more positive experience with 3D learning resources, their cognitive load diminishes, contributing to stronger learning resilience. Well-designed 3D teaching resources facilitate students' intuitive comprehension of concepts and deepen their understanding of course content, thereby reducing cognitive load. A lower cognitive load can make the brain more relaxed, allowing students to efficiently master knowledge and complete tasks. In a relaxed atmosphere, students tend to face learning difficulties positively and address such challenges independently or seek help from others, demonstrating higher learning resilience. This finding underscores the importance of designing 3D learning environments that minimise cognitive load to support student resilience.

Notably, the correlations among 3D learning resources, cognitive load and learning resilience are weak. Possible explanations for this phenomenon lie in the fact that the cognitive load level experienced by students in course learning is impacted by a myriad of factors, including the nature of the courses, disciplinary characteristics, cognitive abilities, learning environments, teaching methods and instructional tools (Klepsch and Seufert 2020; Yu 2022). 3D learning resources represent just one type of modern instructional tool; thus, their impact on cognitive load is limited. Similarly, learning resilience is subject to the influence of various factors, such as social support, parenting styles, student personality and classroom characteristics (Permatasari et al. 2021; Findyartini et al. 2021; Chen et al. 2021; Jowkar 2011), wherein cognitive load is just one contributing factor, thereby resulting in its limited impact. This nuanced understanding bridges our findings with existing research, providing a comprehensive view of the factors influencing cognitive load and learning resilience in educational contexts.

Implications

The present research reveals the mechanism through which 3D learning resources affect the learning resilience of college students using empirical survey data. The results have certain notable implications in terms of both theory and practice. Regarding theory, the contribution of this study is that we construct a theoretical model. The model not only explains the direct and indirect effects of 3D learning resources on learning resilience, but also verifies this indirect effect through two paths. We found that 3D learning resources can indirectly affect learning resilience through cognitive load. As an important theoretical contribution of this study, this conclusion breaks through the existing knowledge system. Therefore, the theoretical model can not only supplement existing findings, but also expand current studies. Additionally, this study expands the theoretical framework surrounding digital learning tools and their psychological effects, and enhances the broaden-and-build theory by demonstrating how 3D learning resources can cultivate positive emotional states and learning resilience among learners.

With respect to practice, this study can provide a basis and suggestions for universities to implement classroom teaching reform and improve their learning outcomes by utilising emerging teaching technologies such as 3D learning resources. First, this study suggests actively building 3D learning resources and integrating them into classroom teaching. As a product of modern computer technology, this study affirms that 3D learning resources can significantly and directly improve students' learning resilience. Therefore, educators must build and use these resources extensively to maximise their positive impact on education. Second, when using 3D learning resources, we should adopt as many interactive ways as possible. By improving the psychological state of students in the learning process, it can enhance their learning resilience and learning effect. For instance, we can integrate relevant explanations, knowledge graphs or thought-provoking questions around 3D learning resources to enhance their learning engagement, reduce cognitive load and thus improve learning outcomes.

Limitations and future research

This study has three main limitations. First, the study relied primarily on cross-sectional survey data and lacked longitudinal tracking data. To better determine the temporal relationship between variables, future research should include time series data and long-term observations of students. Additionally, incorporating methods beyond questionnaires, such as teacher-student interviews and classroom observations, would enhance the robustness of the data. Second, this study only examined the effects of 3D learning resources, positive emotions, and cognitive load on the learning resilience of college students. Other important factors, such as cognitive patterns and personal traits, may also influence learning resilience. Future research should explore these potential variables to provide a more comprehensive understanding. Third, this study was conducted within the current technological context. As

technology continues to advance, the diversity and scope of 3D learning resources are likely to expand. As a result, their impact on students' learning resilience may also evolve. Therefore, future research should consider examining this issue within the latest technological context.

Data availability

The data supporting the findings of this study is available within the supplementary materials of this article.

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Author contributions

Zhihui Ding: Conceptualization, Data curation, Methodology, Investigation, Formal analysis, Visualization, Writing-original draft, Writing-review & editing; Jijun Miao: Funding acquisition, Resources; Yong Yang: Conceptualization, Investigation; Wenlong Zhu: Conceptualization, Funding acquisition, Project administration, Software, Supervision, Validation, Writing-original draft, Writing-review & editing.

Competing interests

The authors declare no competing interests.

Ethical approval

This study was reviewed and approved by the Ethics Committee of Qingdao University of Technology, with the approval number: [QUT20230085] and the approval date: [07-10-2023].

Informed consent

Informed consent was obtained from all subjects involved in the study.

Consent to participate

The participants were informed about the purpose and procedures of this study via an advertisement before the investigation. Moreover, participants were voluntary and anonymous throughout the investigation.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-024-03544-x.

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