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# Exploring the improvement path of virtual simulation experiments: based on the influencing factors and mediating effects of learning satisfaction

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## Abstract

**Background** Virtual simulation experiment is a vital component of higher education digitalization, emerging from the deep integration of specialty disciplines and information technology. Chinese universities have invested heavily in the construction of virtual simulation experiment projects, and the number of projects is considerably large. However, the popularity and effectiveness of these projects are not satisfactory. As an important index to measure the teaching quality, analyzing the influencing factors and mediating effects of learning satisfaction of virtual simulation experiment is an effective entry point to improve the quality and efficiency of virtual simulation experiment teaching and improve the learning effect.

**Methods** This study used quantitative research methods. The research sample includes 538 students from various levels of higher education institutions such as Nanjing University, Nantong University, Nanjing Medical University, and Jiangsu University, covering 11 majors. They started to study the virtual simulation experiment course for one academic year in September 2023 and conducted a questionnaire survey at the end of the course. The questionnaire survey involved four aspects, mainly from the student dimension, course dimension, the technical dimension, and the embodied dimension to evaluate the learning satisfaction of the virtual simulation experiment course. The data were analyzed using SPSS and AMOS.

**Results** According to the results of the structural equation modeling (SEM), all of the student dimension (learning motivation $\{\beta = 0.658, p < 0.001\}$ and task value $\{\beta = 0.339, p < 0.001\}$), course dimension (course content $\{\beta = 0.275, p < 0.001\}$, course flexibility $\{\beta = 0.052, p < 0.002\}$, and course quality $\{\beta = 0.635, p < 0.001\}$), technical dimension (interface design $\{\beta = 0.445, p < 0.001\}$, interaction design $\{\beta = 0.151, p < 0.001\}$, technical adaptability $\{\beta = 0.225, p < 0.001\}$, and technical reliability y$\{\beta = 0.140, p < 0.001\}$), and embodied dimension (social presence $\{\beta = 0.270, p < 0.001\}$ and spatial presence $\{\beta = 0.689, p < 0.001\}$) have positive effects on improving the learning satisfaction of virtual simulation experiments. Meanwhile, the technical dimension exhibited a mediating effect in the influence of embodied dimension on learning satisfaction.

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**Conclusions** To enhance the learning effectiveness of virtual simulation experiments, we can put forward the strategies from four dimensions including students, course, technical, and embodied to specifically address learning satisfaction. This approach would provide directional guidance for the development of medical virtual simulation experiments.

**Keywords** Virtual simulation experiment, Learning satisfaction, The influencing factors, Medical education

## Introduction

Basic medical experiments are crucial in medical education and teaching, as they play a very important role in cultivating students' ability to discover, analyze, and solve problems, and enhancing their innovative thinking ability and creativity [1]. However, in the process of teaching, due to factors such as bioethics, special experimental conditions, high teaching costs and lack of experimental resources, some experiments are difficult to implement under traditional laboratory conditions [2]. As a powerful tool to promote the digital transformation of teaching model in the information age, virtual simulation experiment has gradually become an important auxiliary means of basic medical experimental teaching [3]. It relies on technologies such as virtual reality, multimedia, human–computer interaction, database and network communication technology to build a highly simulated virtual experimental environments and experimental objects, providing a rich learning environment, immersive learning experience, and opportunities for autonomous learning or supplementary learning [4, 5]. It has innovated diverse teaching methods, which is of great significance for deepening education reform and improving the quality of medical education and teaching [6].

Learning satisfaction is not only an outcome index based on learners' opinions, but an important index to measure the quality of a university system [7]. In essence, it reflects the overall experience, emotion and attitude (positive or negative) of the learners towards learning [8]. Studies have shown that learning satisfaction is related to stronger use intention and continuous use intention, and can lead to better learning outcomes [9]. However, currently there are relatively few studies on the effectiveness of virtual stimulation experiment courses [4]. In recent years, there are some problems in virtual simulation experiment resources, such as insufficient technical support, disconnection between learning content and teaching scenarios, and lack of user demand analysis, therefore, it is necessary to investigate the influencing factors of learning satisfaction in virtual simulation experiments [10]. On the one hand, the government and relevant educators in universities can focus on the actual demand of teaching and improve the content and course quality of virtual simulation experiment through scientific top-level design and reasonable teaching planning. On the other hand, curriculum developers can also improve the design and development level of resources according to the determinants of learning satisfaction of virtual simulation experiment, so as to provide students with higher quality virtual simulation experiment. In addition, the research is in line with the student-centered education concept, which helps to understand the subjective needs of learners in the learning process, so as to improve the learning effect and learning persistence of learners [11]. Based on this, this study investigates the learning satisfaction of virtual simulation experiment for the actual teaching scene, and verifies its influencing factors under the guidance of the theory of learning satisfaction, and in combination with the characteristics of virtual simulation experiments. Aiming to provide guidance for higher education institutions in developing high-quality virtual simulation experimental teaching resources and to effectively enhance the effectiveness and practicality of student learning.

## Literature review

According to Islam et al. [12–14], this study defines the learning satisfaction of virtual simulation experiment as the degree of "actual experience perception consistent with personal expectations and needs" after multiple sessions of virtual simulation experiment learning. Previous studies have shown that learning satisfaction of distance education is affected by individual factors, teacher support, course design, real learning situation and other factors [15, 16]. The influencing factors of online learning satisfaction included teaching equipment, course quality, teacher feedback, self-motivation, learning style, interaction and evaluation [17, 18]. Relevant studies mainly focus on the four dimensions of students, teachers, course and technology.

Virtual simulation experiment learning and online learning are both emerging self-directed learning methods. This study believes that the previous scales of learning satisfaction influencing factors of other learning modes are also applicable to the evaluation of virtual simulation experiment learning satisfaction. In the learning process of virtual simulation experimental, learners mainly engage in exploratory learning, while the teacher, acting as the guiding figure, are not involved directly, but

support the virtual simulations through course design. Therefore, this study no longer considers the teacher dimension separately, but expands the scope of the course dimension.

Embodied cognition theory believes that linking learning events with physical behavior will have a greater impact on individual cognition [19]. Virtual simulation technology has immersive characteristics and involves fairly complex learning scenarios. Students can conduct embodied learning by behavioral interaction with the virtual learning environment. Based on the "real learning scenario" [16] of virtual simulation experiments, This study also takes uses the sense of presence as the evaluation index of learning satisfaction in virtual simulation experiment. Therefore, this study divides the influencing factors of learning satisfaction of virtual simulation experiment into student dimension, course dimension, technical dimension and embodied dimension, which contain a total of 12 indicators, as shown in Fig. 1.

#### Student-related factors

Learning motivation refers to students' motivation, willingness and interest in learning courses, which is considered to be an important factor affecting participation [20] and learning outcomes [21]. Learning participation is closely related to satisfaction [22], and learning achievement [23] and academic performance [24] also have positive impacts on student satisfaction, which means that learning motivation may be correlated to learning satisfaction.

Task value is students' understanding of the importance, interest, and practicality of course tasks, which is influenced by students' individual learning needs. When they perceive a higher level of task value, they have a better overall evaluation of learning [25]. Therefore, task value can also have an impact on learning satisfaction in virtual simulation experiments.

Self-efficacy refers to one's ability to believe that he has the capacity to use the platform to learn and successfully complete learning tasks. Self-efficacy affects students' learning process [26], and the learning process directly affects the learning experience, which in turn affects satisfaction.

Therefore, we assume the following:

H1(a) Learning motivation has a positive impact on learning satisfaction in virtual simulation experiment.
H1(b) Task value has a positive effect on learning satisfaction of virtual simulation experiment.
H1(c) Self-efficacy has a positive impact on learning satisfaction of virtual simulation experiment.

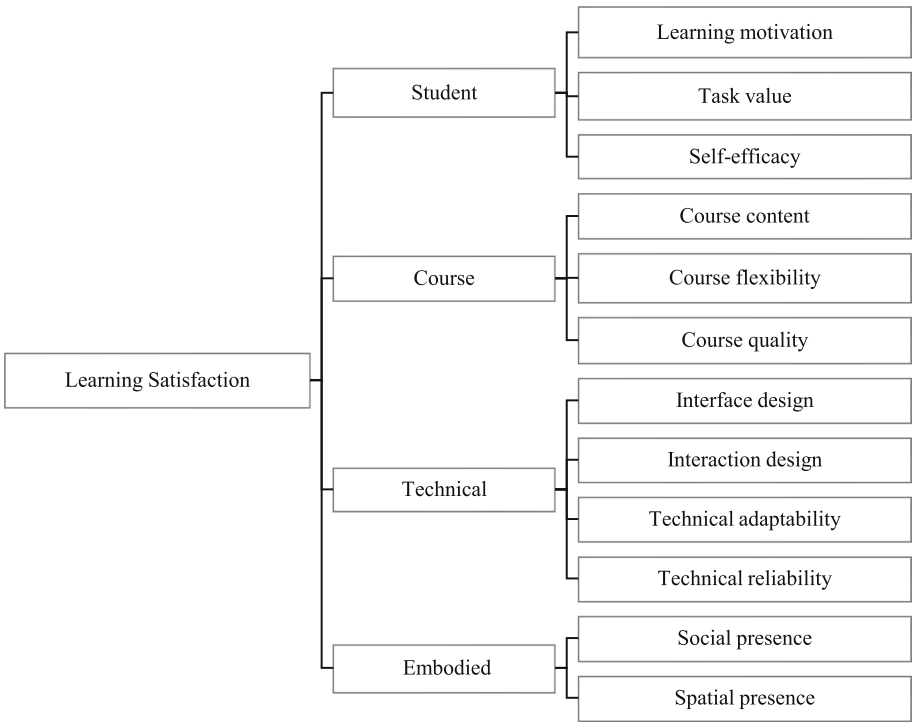


**Fig.1** Variables affecting learning satisfaction in virtual simulation experiment

### Course-related factors

System quality and information quality are the key factors for the success of information system [27], and are also closely related to the user satisfaction of information system [28, 29]. As an experimental operation course based on the virtual simulation experiment platform, the virtual simulation experiment course has both teaching characteristics and information system characteristics. It is believed that the course quality of the virtual simulation course is equivalent to the system quality of the information system, and the course content is the system information. Therefore, it is inferred by analogy that the course quality and course content are closely related to learning satisfaction of virtual simulation experiments.

Virtual simulation experiment is a new teaching method based on students' self-directed learning, which greatly meets the individual needs of learners. Course flexibility refers to the ability of learners to complete their learning tasks without time and space constrains [30]. Studies have shown that the flexibility [31] of e-learning courses can promote learners' participation [32] and satisfaction [33], but no investigation has proved whether it will have an impact on the learning satisfaction of virtual simulation experiments.

Therefore, we make the following assumptions:

H2(a) Course content has a positive impact on the learning satisfaction of virtual simulation experiment.
H2(b) Course flexibility has a positive impact on the learning satisfaction of virtual simulation experiment.
H2(c) Course quality has a positive impact on the learning satisfaction of virtual simulation experiment.

### Technical-related factors

The quality of the interface determines the user's first impression of a software, which is positively related to the user experience [34]. Some studies believe that the course interface is one of the factors that affect students' learning and satisfaction in distance learning [35]. A well-designed course interface is conducive for students to understand the knowledge structure of the course and find important course content or instructions [36].

Learning interaction includes interactions between learners, learners and teachers [37], and learners and content, all of which are reflected in the interaction design of virtual simulation experiments. Interaction design should not only consider the response time and feedback between learners and content, but also should include diverse forms of interaction, such as the course system supporting online interaction between students or between teachers and students. Previous studies have shown that learner-content interaction is beneficial for improving cognitive structure, while peer interaction and teacher-student interaction can improve student learning performance and are positively correlated with online learning satisfaction [38]. This means that learning motivation is likely to be related to learning satisfaction.

The technology acceptance model believes that perceived ease of use will enable learners to develop a positive learning attitude, thereby improving the learning experience and satisfaction [39], and increasing their intention to continue using the technology [40]. In addition, studies have shown that fear of using computers [41] and high level of technophobia can limit learner satisfaction [42]. Therefore, this study incorporates the ease of adaptability and reliability of technology into the research scope of factors affecting learning satisfaction.

Therefore, we assume as follow:

H3(a) Interface design has a positive impact on learning satisfaction of virtual simulation experiment.
H3(b) Interaction design has a positive impact on learning satisfaction with virtual simulation experiment.
H3(c) Technology adaptability has a positive impact on learning satisfaction of virtual simulation experiment.
H3(d) Technology reliability has a positive impact on the learning satisfaction of virtual simulation experiment.

### Embodied-related Factors

Social presence reflects learners' social ability and emotional expression ability in the media environment [43]. The Inquiry Community Theory focuses on the learning process, which is of great significance to the study of presence in the fields of online learning and blended learning. Virtual simulation experiments can build a socialized learning environment, in there, Learners can cooperate to complete tasks, and can engage in social interaction using the chat function or through the facial expressions, body postures, and gestures of virtual characters, thereby realizing the construction and reorganization of cognition. Some studies have confirmed that the enhancement of learners' sense of social presence will positively promote the improvement of their learning effect. So, can social presence affect learners' satisfaction? In addition, combined with the platform attributes and technical characteristics of virtual simulation experiment projects, this study will address that if spatial presence is also an important factor affecting learning satisfaction.

On these grounds, we make the following assumptions:

H4 (a) Social presence has a positive impact on learning satisfaction of virtual simulation experiment.
H4 (b) Spatial presence has a positive impact on learning satisfaction of virtual simulation experiment.

The embodied cognition theory contends that information processing is rooted in the interactive behaviors between learners and the learning environment, closely related to factors such as sensory perception, movement, environmental interaction, and emotions. Traditional experimental teaching often results in an inadequate connection between "cognition" and "body" due to various limitations, lacking a profound sense of learning experience. The intervention and application of educational technology provides environmental support for embodied learning, moreover, virtual simulation experiment presents more situational, immersive and interesting forms because of its technical characteristics. Previous studies have indicated that the interaction between learners and the learning environment is not direct, but rather mediated by technology [44]. Based on this, this study attempts to explore the interaction relationship between technology, learning, and the environment based on following assumptions:

H5(a) Interface design plays a mediating role in the influence of social presence on learning satisfaction.
H5(b) Interaction design plays a mediating role in the influence of social presence on learning satisfaction.
H5(c) Technical adaptability plays a mediating role in the influence of social presence on learning satisfaction.
H5(d) Technical reliability plays a mediating role in the influence of social presence on learning satisfaction.
H5(e) Interface design plays a mediating role in the influence of spatial presence on learning satisfaction.
H5(f) Interaction design plays a mediating role in the influence of spatial presence on learning satisfaction.
H5(g) Technical adaptability plays a mediating role in the influence of spatial presence on learning satisfaction.
H5(h) Technical reliability plays a mediating role in the influence of spatial presence on learning satisfaction.

In order to more intuitively understand the impact of embodied dimension on learning satisfaction of virtual simulation experiment and its mediating mechanism, this paper constructs a theoretical model of "embodied—technical support—learning satisfaction" (as shown in Fig. 2).According to the model, the embodied dimension (social presence and spatial presence) has a direct effect on learning satisfaction, and the embodied dimension has an indirect effect on learning satisfaction through technical support (interface design, interaction design, technical adaptability and technical reliability). So, what are the mediating effects in the model? Is it a partial mediating effect or a complete mediating effect? Which physical dimension and technical dimension have more significant influence on learning satisfaction? These remain to be verified.

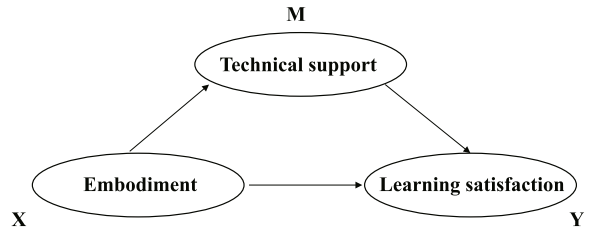


**Fig. 2** The impact mechanism of embodied dimension on learning satisfaction

## Method

### Ethics

The study was conducted in accordance with the ethical standards of the *Ethical Standards of the Declaration of Helsinki*. The research procedures were reviewed and approved by the Institutional Review Committee of Nanjing Medical University (Nanjing Medical University Lun Shen (2023) No. 557, approved on September 20, 2023). Informed consent was obtained from all participants prior to conducting the study, and their personally identifiable information will remain anonymous in all publications. Participants could withdraw from the study at any time without penalty.

### Participants

In this study, virtual simulation experiment teaching activities of basic medicine were carried out using virtual simulation experiment teaching sharing platform of Nanjing Medical University. A questionnaire survey was conducted among the students participating in practical training. Convenient sampling was used in our study, and the respondents were all medical undergraduate students coming from Nanjing University, Nantong University, Nanjing Medical University, Jiangsu University. Finally, 538 questionnaires were collected, of which 487 were valid, with an effective recovery rate of 90.52%. Among the 487 participants, 245 (50.3%) are female and 242 (49.7%) are male. The distribution of majors is shown in Table 1. The surveyed students cover 11 majors, of which clinical medicine students account for more than half, students from other majors are evenly distributed. The

**Table 1** Distribution of sample majors

| Majors | Frequency | Percentage |
|---|---|---|
| Preventive Medicine | 19 | 3.90% |
| Medical Laboratory Technology | 41 | 8.42% |
| Ophthalmological and Optometric Medicine | 16 | 3.29% |
| Clinical Medicine (9-year Bachelor-Master-Doctor Program) | 11 | 2.26% |
| Clinical Medicine (8-year Bachelor-Master Program) | 105 | 21.56% |
| Clinical Medicine (5-year Program) | 166 | 34.09% |
| Clinical Pharmacy | 10 | 2.05% |
| Dental Medicine | 25 | 5.13% |
| Rehabilitation Therapy | 21 | 4.31% |
| Basic Medica | 42 | 8.62% |
| Nursing | 31 | 6.37% |

proportion of students from each major in the collected data is similar to the proportion of students from each major in the total population.

### Questionnaire preparation

This study designed a "Virtual Simulation Experiment Learning Satisfaction Questionnaire", which is divided into two parts: basic information and research subjects. Considering that the students of the basic medical virtual simulation experiment course were mainly sophomores during the research period, the basic information only investigated gender and major. The main research subject included four parts, i.e., students, course, technology, and embodiment, supplemented an open question. To ensure that the questionnaire content was concise and scientific, we organized 30 undergraduates from the Basic Medical College of Nanjing Medical University to participate in a small-scale pre-test in September 2023. Two experts in the field of educational technology and three experts in medical education were invited to evaluate and discuss the items of the questionnaire. According to the results of the test and discussion, the items with high similarity were removed, and unclear expressions were clarified. To ensure the reliability and validity of the variables, the measurement indicators for each hypothetical variable proposed in this study were based on the indicators and question items commonly used in domestic and foreign research. According to the pertinence and characteristics of this study, the measurement items were modified to ensure that they were suitable for the study of satisfaction of virtual simulation experiment. Ultimately, the questionnaire consists 4 dimensions, 12 factors, and 35 measurement items. The dimensions and item information are shown in Table 2. In the subjective task values questionnaires, student responses to Likert-scale questions were coded into numbers ranging from 1 (strongly disagree) to 5 (strongly agree).

## Result

### Reliability and validity test of measurement models

First, in order to better apply the principal component analysis (PCA), a suitability test was conducted on the data. The applicability of the four dimensions that affect the learning satisfaction of virtual simulation experiment was examined using SPSS 21.0. The obtained Kaiser–Meyer–Olkin (KMO) value was 0.955 (>0.9), and Bartlett's sphericity test $p=0.01$ (<0.05), indicating that

**Table 2** Questionnaire Dimensions and Item Information

| Dimension | | The source of the items | Number of questions |
|---|---|---|---|
| Student | Learning motivation | The online course resource learning satisfaction scale was developed by Shi et al. [45] The Cronbach's alphas for each factor were 0.767, 0.860, 0.850, and 0.906, respectively | 3 |
| | Task value | | 3 |
| | Self-efficacy | | 3 |
| Course | Course content | | 3 |
| | Course flexibility | The online learning effectiveness analysis model developed by Hu et al. [46]The Cronbach's alphas were 0.787 | 2 |
| | Course quality | The international student satisfaction model of online course learning interaction developed by Wang et al. [47] The Cronbach's alphas were 0.969 | 4 |
| Technical | Interface design | The online course resource learning satisfaction scale was developed by Shi et al. [45] The Cronbach's alphas for each factor were 0.890, 0.870, respectively | 3 |
| | Interaction design | | 3 |
| | Technical adaptability | The online learning effectiveness analysis model developed by Hu et al. [46]The Cronbach's alphas for each factor were 0.792,0.785, respectively | 3 |
| | Technical reliability | | 2 |
| Embodied | Social presence | The desktop virtual reality environment presence research scale developed by Zhang et al. [48]The Cronbach's alphas for each factor were 0.704, 0.789, respectively | 3 |
| | Spatial presence | | 3 |

the data structure of this group was good and completely suitable for PCA analysis. Then subjected to PCA, and the results are shown in Table 3. From Table 3, the cumulative variance contribution rate of the four principal components reached 91.235% using the method of maximum variance with the extraction of the common factors. In general, the information loss of the original indicators is negligible, and the cumulative variance contribution rate is significantly higher than the threshold of 80%, therefore, these data are worthy of further study.

Finally, SPSS 21.0 and AMOS 28.0 were used to test the reliability and validity of the data to evaluate the measurement model. As the test results shown in Table 4, the reliability of the model was tested by Cronbach's alpha coefficient and combination reliability (CR), and the validity of the model was tested by factor loading and average variation extraction (AVE). It can be seen from Table 4 that the Cronbach's alpha coefficient and combined reliability (CR) of each index are greater than 0.8, indicating that the questionnaire has high reliability. The AVE value of each index and the factor loadings of each item are greater than 0.7, indicating that the model has good convergence. The factor load coefficient of LM3 is 0.476, although it is smaller than other coefficient values, it is very close to 0.5, considering the importance of LM3, so LM3 is still included for analysis.

## Research based on structural equation model

### *Model fit test*

To examine the impact of 12 factors in four dimensions on the learning satisfaction of virtual simulation experiment, this study used AMOS 28.0 statistical software to construct a structural equation model. The main fit indices obtained from the structural model tests are detailed in Table 5. By comparing the given recommended values, it can be found that all other fit indices meet the requirements, except for the chi-square to degree of freedom ratio ($\chi^2$/df) of 3.626. Generally speaking, a structural model with a $\chi^2$/df ratio less than 5 is considered ideal and acceptable. Thus, the model appears to fit the data well.

**Table 4** Measurement indicators' factor loadings, Alpha, CR, and AVE values

| Index | Items | Cronbach's Alpha | Factor Loadings | CR | AVE |
|---|---|---|---|---|---|
| Learning motivation (LM) | LM1<br>LM2<br>LM3 | 0.788 | 0.932<br>0.946<br>0.476 | 0.869 | 0.869 |
| Task value (TV) | TV1<br>TV2<br>TV3 | 0.952 | 0.913<br>0.942<br>0.946 | 0.953 | 0.872 |
| Self-efficacy (SE) | SE1<br>SE2<br>SE3 | 0.964 | 0.955<br>0.956<br>0.932 | 0.964 | 0.898 |
| Course content (CC) | CC1<br>CC2<br>CC3 | 0.943 | 0.917<br>0.907<br>0.940 | 0.944 | 0.849 |
| Course flexibility (CF) | CF1<br>CF2 | 0.874 | 0.942<br>0.833 | 0.883 | 0.791 |
| Course quality (CQ) | CQ1<br>CQ2<br>CQ3<br>CQ4 | 0.926 | 0.900<br>0.869<br>0.843<br>0.868 | 0.926 | 0.757 |
| Interface design (CI) | CI1<br>CI2<br>CI3 | 0.917 | 0.937<br>0.867<br>0.869 | 0.921 | 0.795 |
| Interaction design (ID) | ID1<br>ID2<br>ID3 | 0.937 | 0.922<br>0.928<br>0.892 | 0.938 | 0.836 |
| Technical adaptability (TA) | TA1<br>TA2<br>TA3 | 0.897 | 0.884<br>0.824<br>0.891 | 0.901 | 0.751 |
| Technical reliability (TR) | TR1<br>TR2 | 0.855 | 0.849<br>0.891 | 0.862 | 0.757 |
| Social presence (SP) | SP1<br>SP2<br>SP3 | 0.915 | 0.855<br>0.897<br>0.902 | 0.915 | 0.783 |
| Spatial presence (PP) | PP1<br>PP2<br>PP3 | 0.939 | 0.946<br>0.887<br>0.915 | 0.940 | 0.840 |

### *Hypothesis test results*

The estimated value, T-value and hypothesis test results of standardized path coefficients of each hypothesis are shown in Table 6 and Fig. 3. The findings indicate that the learning satisfaction of virtual simulation experiment is

**Table 3** Total Variance Explained in PCA analysis

| Principal component | Initial eigenvalue | | | Extract sum of squares and load | | | Rotational sum of squares loading | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of variance | Cumulative % | Total | % of variance | Cumulative % | Total | % of variance | Cumulative % |
| 1 | 8.916 | 81.053 | 81.053 | 8.916 | 81.053 | 81.053 | 3.445 | 31.315 | 31.315 |
| 2 | 0.468 | 4.252 | 85.305 | 0.468 | 4.252 | 85.305 | 2.937 | 26.698 | 58.014 |
| 3 | 0.368 | 3.345 | 88.650 | 0.368 | 3.345 | 88.650 | 2.123 | 19.304 | 77.317 |
| 4 | 0.284 | 2.585 | 91.235 | 0.284 | 2.585 | 91.235 | 1.531 | 13.918 | 91.235 |

**Table 5** Model fitting parameters

| Model fitting index | Initial value | Recommended value |
|---|---|---|
| $\chi^2$ | 250.183 | - |
| df | 69 | - |
| $\chi^2$/df | 3.626 | < 3 |
| GFI | 0.931 | > 0.9 |
| AGFI | 0.894 | > 0.8 |
| RMSEA | 0.074 | < 0.08 |
| NFI | 0.975 | > 0.9 |
| CFI | 0.982 | > 0.9 |
| IFI | 0.982 | > 0.9 |

**Table 6** Hypothesis test results

| Hypothesis | *β* | *P* | *T*-value | Result |
|---|---|---|---|---|
| LM | 0.658 | *** | 11.227 | Support |
| TV | 0.339 | *** | 3.599 | Support |
| SE | -0.037 | 0.623 | -0.492 | Not supported |
| CC | 0.275 | *** | 12.031 | Support |
| CF | 0.052 | 0.002 | 3.145 | Support |
| CQ | 0.635 | *** | 21.115 | Support |
| CI | 0.445 | *** | 18.102 | Support |
| ID | 0.151 | *** | 7.568 | Support |
| TA | 0.225 | *** | 10.833 | Support |
| TR | 0.140 | *** | 5.471 | Support |
| SP | 0.270 | *** | 12.867 | Support |
| PP | 0.689 | *** | 25.710 | Support |

*Abbreviations*: *β* Path coefficient, *LM* Learning motivation, *TV* Task value, *SE* Self-efficacy, *CC* Course content, *CF* Course flexibility, *CQ* Course quality, *CI* Interface design, *ID* Interaction design, *TA* Technical adaptability, *TR* Technical reliability, *SP* Social presence, *PP* Spatial presence

affected by learning motivation, task value, course content, course flexibility, course quality, interface design, interaction design, technical adaptability, technical reliability, social presence, and spatial presence. Therefore, it supports the hypotheses H1(a), H1(b), H2(a), H2(b), H2(c), H3(a), H3(b), H3(c), H3(d), H4(a), and H4(b). Surprisingly, self-efficacy had no significant effect on learning satisfaction in virtual simulation experiment, hence not supporting hypothesis H1(c).

#### *Mediation effect analysis*

From the perspective of embodiment, technical means have a significant impact on the sense of embodied. To examine the role of technical means in the causal path between embodied dimension and satisfaction of virtual reality experimental teaching, we tested the mediation effect of technical dimension, embodied dimension, and learning satisfaction. This test was performed with bias-corrected non-parametric percentile bootstrap resampling 2000 times, and 95% confidence intervals were calculated, and the results are presented in Table 7. The results show that both social presence and spatial presence indirectly influence learning satisfaction through the mediation of interface design, technical adaptability, and technical reliability. Unexpectedly, interaction design exhibits no mediation effect on the effect of spatial presence on learning satisfaction. On the whole, the results indicate that the effect of embodied dimension on learning satisfaction is mediated by technical dimension. Moreover, compared with the mediation effect of spatial presence on learning satisfaction, the mediating effect of spatial presence on learning satisfaction through technical dimension is more pronounced.

## Discussion

This study based on a thorough review of relevant literature, constructed a structural equation model to explore the relationships between the dimensions of student, course, technical, and embodied, and learning satisfaction. The aim was to reveal the mechanisms through which these dimensions affect learning satisfaction, as well as the mediating role of the technical dimension in the relationship between the embodied dimension and learning satisfaction.

### The impact of student dimension on learning satisfaction

Based on a large number of relevant literatures, this study summarizes four independent variables that may affect college students' learning satisfaction in virtual simulation experiments. From the perspective of students' individual dimension, there is a significant correlation between students' learning motivation and learning satisfaction, and task value is also one of the factors affecting learning satisfaction. This research result is consistent with the findings of Moghadari et al. [49] and Abdulrahman et al. [50] This is because strong learning motivation encourages students to actively participate in learning activities, and when students recognize the value of tasks, they are more willing to engage in them, thereby improving learning satisfaction. Teachers can design challenging tasks in virtual simulation experiments to stimulate students' curiosity and exploratory desire. At the same time, teachers should clearly demonstrate the application scenarios of learning outcomes, ensuring that tasks are relevant to students' future career development or daily life, thus enhancing their perceived task value.

Surprisingly, self-efficacy had no significant effect on learning satisfaction in virtual simulation experiments. This is inconsistent with the research results of Mousavi et al. [51] and Choi et al. [52]. The underlying reasons for this discrepancy can be attributed to two main factors. On the one hand, when learners are confronted with

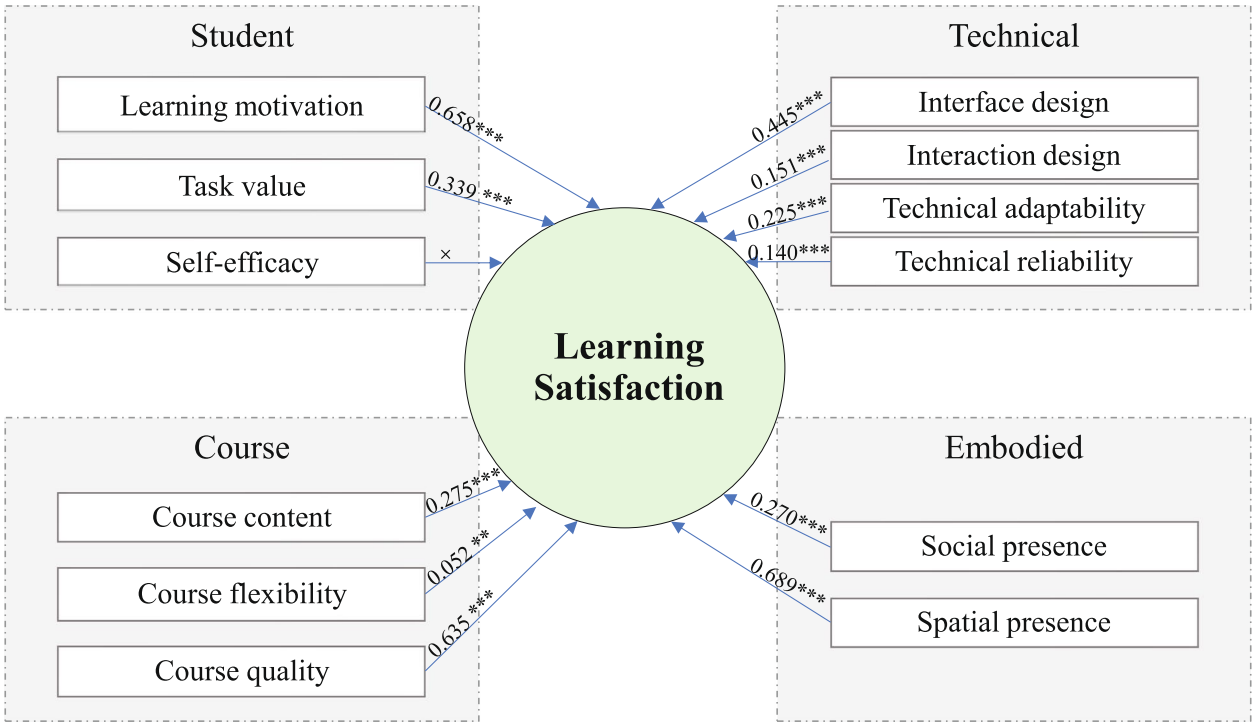


**Fig. 3** Path coefficient analysis in structural equation models

**Table 7** Results of mediation tests

| Hypothesis | Total effect size | Intermediate effect size | BootSE | 95% Confidence interval | | Hypothesis testing |
|---|---|---|---|---|---|---|
| | | | | LLCI | ULCI | |
| SP → CI → LS | 0.2916 | 0.1096 | 0.0233 | 0.0653 | 0.1560 | Support |
| SP → ID → LS | 0.2916 | 0.0846 | 0.0226 | 0.0444 | 0.1339 | Support |
| SP → TA → LS | 0.2916 | 0.1038 | 0.0226 | 0.0612 | 0.1496 | Support |
| SP → TR → LS | 0.2916 | 0.0856 | 0.0220 | 0.0446 | 0.1291 | Support |
| PP → CI → LS | 0.3065 | 0.0797 | 0.0244 | 0.0313 | 0.1270 | Support |
| PP → ID → LS | 0.3065 | 0.0443 | 0.0243 | -0.0029 | 0.0921 | Not support |
| PP → TA → LS | 0.3065 | 0.0852 | 0.0202 | 0.0481 | 0.1275 | Support |
| PP → TR → LS | 0.3065 | 0.0629 | 0.0219 | 0.0248 | 0.1098 | Support |

*Abbreviations*: *CI* Interface design, *ID* Interaction design, *TA* Technical adaptability, *TR* Technical reliability, *SP* Social presence, *PP* Spatial presence, *LS* Learning satisfaction, *LLCI* Lower limit of the 95% confidence interval, *ULCI* Upper limit of the 95% confidence interval

the rich functions of virtual simulation projects, they may easily experience information overload. This results in wasted time and energy, thereby diminishing the evident impact of self-efficacy. On the other hand, learners might harbor excessively high or unrealistic expectations for virtual simulation experiments, and when the actual experience fails to meet these expectations, it consequently hampers the positive effects of self-efficacy. These factors are likely the primary reasons for the mismatch between expectations and outcomes. Therefore, teachers can provide sufficient guidance during students' learning to help those with lower technical proficiency overcome technical barriers in virtual simulation experiments. Education decision-makers can consider developing strategies to help students set reasonable expectations and provide sufficient resources to ensure they can learn efficiently in virtual environments.

#### The impact of course dimension on learning satisfaction

Previous studies have shown that course dimension is one of the influencing factors of learning satisfaction, and this study confirms that the same applies to virtual

simulation experiments. The results show that course quality has a significant positive impact on learning satisfaction in virtual simulation experiments. For course content, course knowledge with a rich structure, up-to-date with the discipline's frontier, and linked to practical applications is more likely to be favored by students. This also, to some extent, confirms the views of Hu et al. [46]. It can be seen that, regardless of the external expression form of technology, the course content is always the core of the course. In order to provide students with higher learning satisfaction, teachers should carefully arrange the structure of course content, enrich course resources, and strengthen the connection between knowledge and practical application. The government and universities can establish standards to evaluate the quality of virtual simulation experiments and provide incentives for teachers to develop high-quality courses.

The research data shows that course flexibility has no significant impact on the learning satisfaction of virtual simulation experiments. This is inconsistent with the research results of Hale et al. [53] and Golan [54] in the context of online courses. The reason for this is that, compared to online courses, the operation of virtual simulation experiments has higher requirements for terminal devices, and the learning progress cannot be saved after project submission, which requires students to use relatively complete time for learning. Therefore, the course has certain limitations on the learning space of students, which may be the main reason for the insignificant impact. Teachers can refine course objectives and divide virtual simulation experiments into multiple task modules, with each module scored separately. This allows students to utilize fragmented time for planning and completing tasks, achieving flexible learning within the course. In addition, companies or institutions can be commissioned to upgrade existing virtual simulation experiments to web-based access modes, making it easier for students to access these resources without needing to install plugins.

#### The impact of technical dimension on learning satisfaction

Technical support is also an important predictor of satisfaction in learning virtual simulation experiments. High usability in course interface design and interactive design, coupled with robust security and stability of the platform, enables students to utilize virtual simulation projects conveniently and confidently, thereby enhancing their acceptance of this mode of experimental learning. The research results of Eom et al. [55] and Yalcin et al. [56] also confirmed this viewpoint. On one hand, through online platforms, learners can conduct virtual experiments without spatial constraints, fulfilling the needs of diverse learning scenarios and augmenting the convenience and satisfaction of the learning process. On the other hand, virtual simulation experiment platforms can tailor learning content based on the learner's abilities, progress, and preferences, offering personalized learning paths and feedback. This ensures that each learner can study at a pace and difficulty level tailored to their needs, facilitating the achievement of learning objectives. Consequently, reinforcing the technical design of virtual simulation experiments emerges as an effective strategy for enhancing the satisfaction of university students in their learning endeavors. Universities and institutions should invest in constructing and maintaining technological infrastructure to ensure that all students have access to virtual learning resources.

#### The impact of embodied dimension on learning satisfaction

The embodied dimension also exerts a high predictive power over the learning satisfaction derived from virtual simulation experiment. At present, there is no relevant research that considers the embodied dimension as a separate factor affecting learning satisfaction. This study indicates that spatial presence has a significant correlation with learning satisfaction, and it positively influences learning satisfaction through the mediation of interface design, technical adaptability, and technical reliability. Virtual simulation experiments provide highly realistic visual, auditory, and even tactile feedback, enhancing learners' immersive experience. By simulating real experimental environments and operating equipment, students can more intuitively understand and master the experimental process, which can enhance their learning interest to a certain extent. Teachers should strengthen the design of virtual simulation experiments based on embodied cognition theory, promoting students' deep understanding and skill mastery by creating a more intuitive and interactive learning environment. This means that experimental design should focus on simulating real-world physical interaction processes, allowing students to experience and perceive scientific principles through virtual operations. This approach better connects abstract concepts with practical situations, enhancing knowledge transfer abilities and problem-solving skills.

Social presence is also positively associated with learning satisfaction and, through technical mediation, contributes positively to it. Virtual simulation experiment platforms facilitate communication and collaboration among learners, as well as between learners and intelligent teaching assistants. These platforms also enhance learners' patient examination and communication skills through interactions with ESP (electronic standardized patient), thereby augmenting the social and engaging aspects of learning and elevating overall satisfaction with

the learning experience. In the future, teachers should focus on designing multi-user interaction features, creating realistic virtual characters, and providing real-time feedback mechanisms to enhance social presence in virtual reality simulations. This will enable students to experience social interactions similar to those in the real world even within virtual environments.

### Mediating effect

The mediation effect analysis indicates that technical support plays a mediating role in promoting the improvement of learning satisfaction in the embodied dimension. This expands and extends the views of scholar Zhong [44]. Undoubtedly, the role of technology-embodied in the learning process is becoming increasingly significant. Most existing virtual simulation experiments primarily facilitate visual and auditory perceptual interactions for learners, thereby enhancing the sense of immersion in the learning environment and promoting both the acquisition of knowledge and an elevation in learning satisfaction. From a fundamental perspective, technology inherently resides between the body and its environment, utilized by the body, coupled with it, acting upon it, and concurrently providing feedback about the environment. This inherent integration of technology within the learning experience underscores its capacity to bridge the gap between learners and the digital realm, fostering a more comprehensive and satisfying educational encounter.

### Limitation

This study has limitations. The results are based on a small and homogeneous sample from several universities within Jiangsu Province; therefore, the findings may not be applicable to all virtual reality experimental programs. This article aims to select a far wider range of data in future research and adjust model variables to make the virtual simulation experiment learning satisfaction influencing factor model more universal, thereby improving the generalizability of the research results. In addition, the study also used a cross-sectional design, which limited the ability to infer causal relationships between the research variables.

## Conclusions

As a powerful tool to promote the digital transformation of teaching mode in the information age, virtual simulation experiment has gradually become an important auxiliary means of basic medical experimental teaching. As the educational concept of 'autonomous learning' continues to advance and deepen, the student experience of virtual simulation experiments has become an important factor in determining its development.

Firstly, the course structure of virtual simulation experiments should be expanded, with a focus on refining the holistic design of course content, constructing a clear hierarchical framework of knowledge, integrating multiple disciplines, and enhancing the advanced design of course materials to meet the diverse learning needs of students at different stages. Secondly, efforts should be intensified to merge technologies, creating embodied presence experiences, fostering an open learning community, and promoting online collaboration and communication among teachers, students, and peers, while also reinforcing the authenticity and stability of human–computer interactions. Lastly, with students at the core, personalized learning pathways should be devised, leveraging progressive challenges and immediate feedback mechanisms to boost student motivation and self-efficacy. Future research could pivot its focus onto the instructors of virtual simulation experiments, rather than solely on the students themselves. Overall, our research emphasizes the adaptability and effectiveness of virtual simulation experiments in medical education, particularly their emphasis on the use of embodied environments to prepare students for the evolving curriculum and challenges in the field of medical education.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-06082-x.

Supplementary Material 1.

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### Authors' contributions

H.Z.W. contributed substantially to the study design and the writing of manuscript Q. Q.L. contributed to the analysis and interpretation of data. Y.B.Y. supervised the project and revised the manuscript. H.Z.W. and Y.B.Y. participated in acquisition of data. All authors read and approved the final manuscript.

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### Availability of data and materials

The datasets used and/or analyzed during the present study are available from the corresponding author upon request.

## Declarations

### Ethics approvals and consent to participate

The study was approved by the Ethics Committee of Nanjing Medical University (Approval No. 2023 – 557). Methods were carried out in accordance with relevant guidelines and regulations. Informed consent was obtained from all participants.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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