Influencing Factors of Virtual Simulation Experiment Teaching Effect Based on SEM

https://doi.org/10.3991/ijet.v17i18.34489

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Abstract—Virtual simulation experiment teaching has been extensively applied to higher education. Recognizing the influencing factors of virtual simulation experiment teaching effect and analyzing the influencing strength of each factor has become a highly concerning problem in the education circle. To improve the virtual simulation experiment teaching effect effectively and make feasible optimization measures, influencing factors were first reviewed and analyzed in this study based on previous research from four perspectives of engagement of students, the academic basis of students, virtual simulation experiment design, and teachers' guiding. Second, the conceptual model and structural equation model (SEM) to analyze the virtual simulation experiment teaching effect were constructed by the SEM analytical method. On this basis, nine hypotheses of the model were designed. Finally, a case study based on the three built virtual simulation teaching projects was conducted. The significance of the influencing factors on the teaching effect was verified through questionnaires, SPSS analysis, and AMOS software. The acting path and influencing the strength of influencing factors were analyzed. Some strategies and measures to improve the virtual simulation teaching effect were proposed. Results demonstrated that virtual simulation experiment design is the primary influencing factor of the teaching effect, followed by engagement of students, teachers' guiding and academic basis of students successively. Conclusions can provide theoretical support and decision-making references to formulate strategies for improving virtual simulation experiment teaching.

Keywords—virtual simulation, teaching effect, SEM analysis, acting path, experiment course

1 Introduction

The practical ability of college graduates is closely related to the social-economic level. Strengthening the students' practical ability through various modern information technology and high-quality experimental resources has become widely accepted as technical means in the current academic circle [1, 2]. Virtual simulation teaching experiment is the product of the deep integration of virtual reality technology and disciplines and majors. Not only can it provide students good sense of immersion and achievement, but also motivates their enthusiasm and initiatives in experimental practice activities [3]. Possible dangers in "high-cost," "high-consumption," and "high-risk" practice links that are needed can be avoided through the virtual environment, while the problem of practice teaching resource shortages is solved effectively [4]. Although virtual simulation experiment teaching has achieved good promotion effects in stimulating the students' learning interests and knowledge comprehension, it still has the phenomenon that some students "cannot learn", "cannot understand" and "fail in the exam". Therefore, recognizing influencing factors of virtual simulation experiment teaching quality scientifically and analyzing interaction mechanisms of influencing factors are prerequisites to formulate the teaching organization.

Nevertheless, existing studies focused on applications of virtual simulation technologies to practice teaching higher education. Key attention is paid to design of curriculum resources, script logic, experimental procedure, simulation effect, operation interface and curriculum management [5, 6]. However, satisfaction and behavioral initiatives of students in the simulation experiment are ignored to some extent. The virtual simulation experiment teaching effect is mainly investigated through experimental reports and after-class exercises of students nowadays [7, 8]. However, it lacks studies and tests on the students' satisfaction and their knowledge acquisition and practice ability training in the experimental process. Studies on virtual simulation experiment teaching generally emphasize on the analysis of curriculum design and experimental script logic, but lack discussions of multi-dimensional collaborative interactions (e.g. engagement of students and teachers' guiding) on teaching quality. Hence, influencing factors of virtual simulation experiment teaching quality were reviewed systematically from the perspectives of engagement of students, academic basis of students, virtual simulation experiment design, and teachers' guidance. The acting path and influencing strength of influencing factors were determined. Specific strategies for improvement of teaching quality were proposed to assure the practical effect of virtual simulation experiment teaching in higher education.

2 Literature review and research hypotheses

2.1 Literature review

Previous studies mainly recognize and screen influencing factors of virtual simulation experiment teaching quality through the students' exam result summary and comparison. For example, Smith et al. [9] examined Foley catheter skill training of students who majored in medical nursing and tested performance differences of students who have participated in virtual simulation teaching by experimental performances and independent sample t-test in statistics. Williams et al. [10] conducted virtual simulation experimental training of professional nursing knowledge to students of various majors and tested the profession of trained students in nursing patients. They determined that virtual simulation teaching can encourage interdisciplinary students to strengthen their understanding of nursing skills. He et al. [11] built a virtual simulation experiment teaching platform of an unmanned aerial vehicle (VSETP-UAV) for the teaching activities of UAV digital mapping and remote sensing major at Wuhan University, China. They determined that the functional design, teaching strategies, and experimental method of virtual simulation teaching are key factors to improve teaching quality effectively. By comparing the performance of students using virtual simulation teaching or not in the vocational education application technology curriculum, Damasceno et al. [12]

determined that the virtual experiment is not only an effective tool to improve learning enthusiasm of students, but is also a way of high-quality knowledge acquisition and a teaching mean of lowering cost. Through the virtual simulation teaching case study in a training company of Ukraine professional technology, Kashyna et al. [13] determined that virtual simulation teaching technology can improve the trainees' leaning efficiency and lower error rates in practical operation. Simulation authenticity of experiment is the key that influences the training effect. Alsuwaidi et al. [14] divided students in medical blood curriculum into two groups according to whether they have received virtual simulation experiment teaching. Based on the Kirkpatrick model, the teaching effects of two groups were evaluated in the hematological teaching experiment. They determined that virtual simulation teaching technology can strengthen the teaching quality of medical courses during the undergraduate program. Wang [15] developed the virtual simulation experiment course for physical education in universities based on artificial intelligence and evaluated the teaching effect by using the neural network analysis. Results demonstrated that 35% students of the virtual teaching experiment group achieved excellent performance, while only 10% of the control group without virtual teaching achieved excellent performance. Peng et al. [16] developed a set of virtual simulation experiment system of gunpowder combustion based on the WebGL virtual simulation technology. By comparing the teaching application and teaching effect, they determined that the experimental system has some value to improve teaching effect and guarantee experimental safety of students. Zhang et al. [17] introduced the virtual simulation technology into the printing and package experimental teaching and reproduced the working scene of printer. They conducted a comprehensive virtual printer experiment from four aspects, which include experimental design, experimental operation, evaluation of printing sample number and fault practice results. Through the operation of virtual printers, students can master the operation process of the printer quickly and accumulate experience in solving faults through the fault question library.

Although existing applications of virtual simulation teaching technology have covered various professional fields in higher education, existing studies focused on simulation technologies such as virtual scenes and experimental process design of virtual simulation teaching. Nevertheless, influences of relevant soft constraints such as the engagement of students and teachers' guidance on simulation teaching quality were ignored. Previous studies focus on assessment results of students in demonstrating and verifying validity of the virtual simulation teaching method, but they lack attention to the acting path and influencing strength of influencing factors.

Therefore, factors that restrict virtual simulation experiment teaching quality were reviewed and recognized from four perspectives of the teachers' guidance, engagement of students, academic basis of students and simulation design. Combining with case study and questionnaire survey, influencing factors were extracted and defined. The acting path and influencing strength of factors were analyzed by the structural equation model (SEM). Results provide educators some references in formulating measures to optimize the design and teaching process of virtual simulation experiment teaching.

2.2 Research hypothesis

Virtual simulation experiment teaching effect is mainly measured by evaluating the teaching process and teaching effect [19]. In view of the curriculum characteristics of virtual simulation, the real scenes were perceived through virtual simulation technology, based on which the evaluation scale of teaching effect was designed. In this study, the measurement indices of teaching process evaluation and students' satisfaction were added to the analysis of teaching effect. Virtual simulation experiment teaching cannot be realized without software support using scientific technology as the carrier. Through the teachers' guidance on the simulation experiment platform, students can analyze, study, and discuss experimental tasks in the virtual scene, as well as accomplish objective assessment, thus improving practice ability of students. Hence, the virtual simulation experiment teaching effect shall be analyzed from the perspectives of student engagement, academic basis of students, simulation design and the teachers' guidance. How these factors influence mutually and affect the teaching effect shall be analyzed rather than evaluated according to the academic performance of students. Combined with previous studies [20], the engagement of students, academic basis of students, simulation design, and the teachers' guidance were used as latent variables of the SEM and a conceptual model of the SEM was constructed (Figure 1). Relevant hypotheses are proposed to analyze the influencing strength of teaching effect.

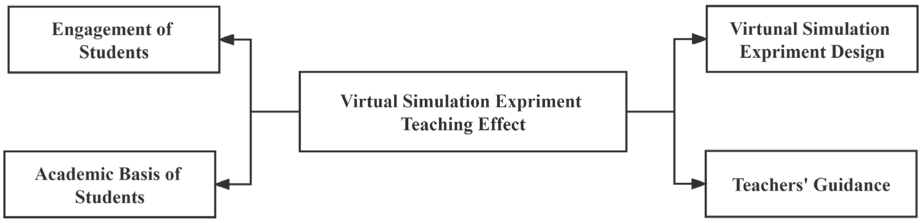

Fig. 1. Conceptual model for virtual simulation experiment teaching effect analysis

The research hypotheses are proposed:

H-1: Engagement of students has a positive influence on virtual simulation experiment teaching effect.
H-2: Academic basis of students has a positive influence on virtual simulation experiment teaching effect.
H-3: Virtual simulation experiment design has a positive influence on virtual simulation experiment teaching effect.
H-4: Teachers' guidance has a positive influence on virtual simulation experiment teaching effect.
H-5: Engagement of students has a positive influence on teachers' guidance.
H-6: Teachers' guidance has a positive influence on the engagement of students.
H-7: Academic basis of students has a positive influence on their engagement of students.
H-8: Virtual simulation experiment design has a positive influence on the engagement of students.
H-9: Virtual simulation experiment design has a positive influence on the teachers' guidance.

3 Methodology

3.1 Variables

In the design of observation variables, associated studies were reviewed and observation variables were screened according to the engagement degree of students, academic basis of students, virtual simulation experiment design and teachers' guiding. The engagement of students is measured by their subjective cognition of the course necessity, perception of the course interestingness, and learning enthusiasm. Academic basis of students is measured by the acquired professional basic knowledge of the course, adaptation to virtual simulation experiment, and prepared basic knowledge. The virtual simulation experiment's design quality will surely influence the teaching effect and observation variables, which include the stability of the virtual simulation experiment system, beauty of virtual simulation experiment design interface, appropriateness of hints in the experimental system, and the richness of the built-in resources of the experimental system. Teachers introduce the whole simulation teaching process. They would influence the teaching effect of a course mainly through the timeliness of guidance, reasonability of the experimental arrangement, and so on. A model composed of 15 observation variables was built. In Table 1, indices of engagement of students, academic basis of students, virtual simulation experiment design, teachers' design, and virtual simulation teaching effect were expressed by A1, A2, A3, A4, and A5, respectively.

Table 1. Selection of observation variables of virtual simulation experiment teaching

Latent Variables	Observation Variables	Indicator Source
Engagement of students A1	X1: the necessity of experiment course	References [7, 20]
	X2: interestingness of course	References [21]
	X3: time needed to finish the experiment	References [4, 9]
Academic basis of students A2	X4: prepared basic knowledge requirements	References [22]
	X5: the acquired basic knowledge of simulation experiment	References [3, 9, 22]
	X6: Difficulty of simulation experiment	References [23]
Virtual simulation experiment design A3	X7: stability of virtual simulation experiment design	References [11, 24]
	X8: beauty of virtual simulation experiment design	References [25, 25]
	X9: understandability of simulation experiment hints	References [26]
	X10: richness of simulation experiment resources	References [26]
Teachers' guiding A4	X11: providing essential teaching tools or not	References [27]
	X12: provided guidance in simulation experiment	References [12, 27]
	X13: reasonability of simulation experiment arrangement	References [6, 17]
Simulation experiment teaching effect A5	X14: simulation learning satisfaction	References [28]
	X15: knowledge quality acquired from simulation experiment	References [22, 28]

Observation variables may have some measuring errors or residual errors (e). Based on the hypotheses above, the SEM of the virtual simulation experiment teaching effect could be gained by AMOS software (Figure 2).

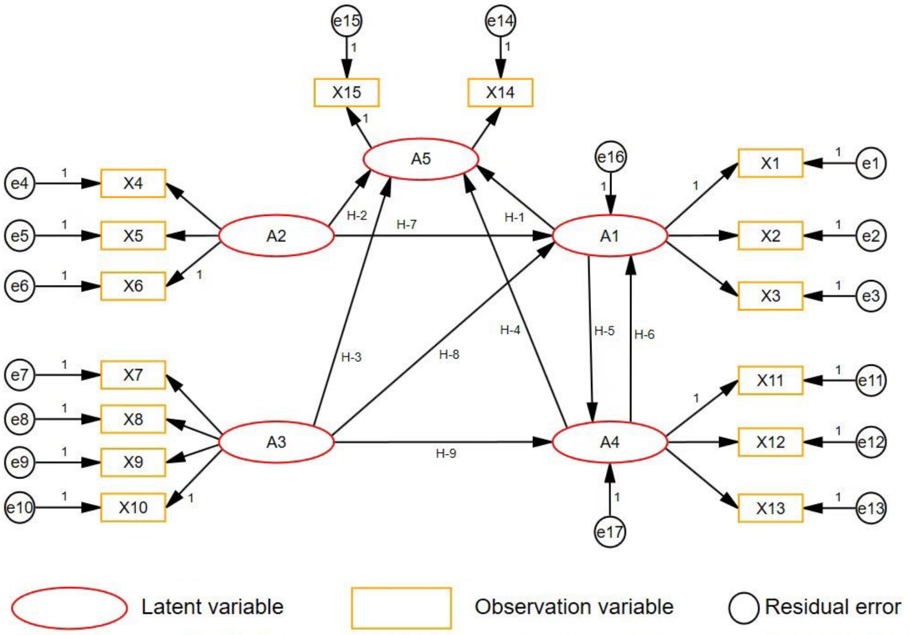

Fig. 2. SEM of virtual simulation experiment teaching effect

3.2 Questionnaire design and data collection

A case study based on the virtual simulation experiment course for majors (e.g., Aviation Safety Engineering, Aviation Service Art and Management, as well as Air Traffic Control and Dispatch and Flying Skill) of Civil Aviation in Zhengzhou University of Aeronautics was conducted in this study. Three simulation experiment teaching projects in the university, which include "Emergency Evacuation of Civil Aviation", "Emergency Collaborative Rehearsal in Airports," and "Emergency Rescue in Passenger Cabin of Civil Aviation," were used in this study. Data were collected through a questionnaire survey immediately after finishing the experiment from March 2 to March 20, 2022. The simulation experiment course is shown in Figure 3.

Fig. 3. Virtual simulation experiment teaching scenes of "emergency collaborative rehearsal in airports"

The questionnaire was divided into three parts. Part I is the preface of the questionnaire, which shows the objectives and contents of this survey. Part II contains the characteristic information of survey objects, including the name, gender, profession, simulation experimental project, and so on. Part III is the theme subject of the questionnaire and it involves measurement questions related with the "virtual simulation experiment teaching effect". In the design of latent variables, the engagement of students, academic basis of students, virtual simulation experiment design and the teachers' guiding were used as influencing factors of teaching effect. A total of 450 questionnaires were sent to students participating in the virtual simulation experiment, among which 436 valid ones were collected. The recovery rate was 96.9%. A five-point Likert scale was applied in the questionnaire survey. Five answers were optional to each question, which comprise Strongly Agree, Agree, Moderate, Disagree, and Strongly Disagree.

4 Results analysis and discussion

4.1 Sample reliability and validity tests

Reliability and validity were two major indices to evaluate quality of questionnaire survey results. Reliability was expressed by Cronbach's α. The value interval of Cronbach's α in different subscales was 0-1. When Cronbach's α was higher than 0.7, the questionnaire survey data in this study has high reliability and can be used to study further. The Cronbach's α of statistical variables in the questionnaire survey could be gained in SPSS (Table 2).

Table 2. Reliability analysis results of latent variables

Type of Latent Variables	Number of Latent Variables N	Cronbach's α
Engagement of students	3	0.782
Academic basis of students	3	0.881
Virtual simulation experiment design	4	0.947
Teachers' guiding	3	0.915
Simulation experiment teaching effect	2	0.936

Table 2 shows that Cronbach's α of five latent variables is higher than 0.7, indicating that the internal consistency of this scale is stable. Therefore, the questionnaire design is reasonable and the acquired data can be used for further analysis.

Validity is the standard that reflects accuracy and effectiveness of survey data. It includes content validity and structural validity, which were expressed by KOM and Bartlett's Test. When KMO is higher than 0.7, the scale data can be used for factor analysis. If the significance level of Bartlett's Test is smaller than 0.05, questions in the scale may be used to extract common factors. The KMO and Bartlett's test results of statistical variables in the questionnaire could be gained through SPSS (Table 3).

Table 3. Validity test results of influencing factors

Number of Applicableness of KMO		0.924
Bartlett's Test	Approximate Chi-square	2528.327
	Degree of freedom (DOF)	164
	Significance	0

KMO value of the pre-test questionnaire is 0.924 (>0.7), indicating that the scale is applicable to the factor analysis. The approximate Chi-square of Bartlett's test is 2528.372 and the DOF is 164. The significance level (P) is only 0 (<0.01), passing through the significance test on the 1% level. Hence, this scale applies to the factor analysis. This study extracts five factors and the cumulative variance interpretation rate of factors is 71.06%. The factor load of various components is higher than 0.5, indicating that all components have high explanatory strength and the questionnaire survey has good validity.

4.2 Fitting test

The model test and analysis were conducted using AMOS. The overall fitting coefficients are gained in Table 4. The chi-square/DOF is 2.763 (<3), indicating that the model has good fitting effect. Moreover, RMSEA is 0.007 (<0.05). GFI, NFI, RFI, IFI and TLI are higher than 0.9, indicating that the model is built well and the model results are reliable.

Table 4. Overall fitting coefficients of the model

Fitting Value	χ^2/df	GFI	AGFI	CFI	IFI	RMSEA	TLI
Standard values	<3	>0.9	>0.9	>0.9	>0.9	<0.05	>0.9
Actual value	2.763	0.957	0.961	0.984	0.932	0.007	0.977
Fitting results	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified	Qualified

4.3 Test of research hypotheses

The hypotheses test was performed to the SEM. Test results are shown in Table 5. All hypotheses passed the test except H-7.

Table 5. Hypotheses results

Hypotheses	Normalized Path Coefficient	*P*	Test Results
A5<−A1	0.291	***	significant
A5<−A2	0.166	0.017	significant
A5<−A3	0.412	***	significant
A5<−A4	0.207	***	significant
A4<−A1	0.133	0.034	significant
A1<−A4	0.325	***	significant
A1<−A2	0.187	***	significant
A1<−A3	0.379	***	significant
A4<−A3	0.226	0.061	false

Notes: *** means that when the restriction probability value is $P<0.001$, the hypothesis is very significant. When $P>0.05$, the hypothesis is false.

The normalized path coefficient of H-1 is 0.291 ($P<0.001$). Therefore, the students' engagement has significant influences on virtual simulation experiment teaching. This indicates that students who input more efforts and time to virtual simulation experiment teaching have the stronger concentration and acquire more practice knowledge from the virtual simulation experiment teaching platform. As a result, the virtual simulation experiment teaching effect is better.

The normalized path coefficient of H-2 is 0.166 ($P=0.017$). Therefore, the academic basis of students has significant influences on virtual simulation experiment teaching. However, academic basis has smaller influences compared with the other three latent variables because students usually learn basic knowledge of the experiment according to guidance of the virtual simulation experiment platform in advance.

The normalized path coefficient of H-3 is 0.412 ($P<0.001$). Therefore, virtual simulation experiment design has significant influences on virtual simulation experiment teaching. It is the primary influencing factor of teaching effect among four latent variables. It indicates that the stability and beauty of virtual simulation experiment design, understandability of simulation experiment hints, and richness of simulation experiment resources are vital to the teaching effect. Because the new learning mode and strongly interactive virtual simulation experiment design can easily improve learning interest and enthusiasm of students in finishing the experiment, thus improving the teaching effect of the course from students themselves.

The normalized path coefficient of H-4 is 0.207 (P<0.001). Therefore, the teachers' guidance has significant influences on virtual simulation experiment teaching. This indicates that the teachers' teaching and interpretation of professional knowledge can still influence experiment teaching effect to some extent, although there are contents and modules related with knowledge interpretation and experiment guiding on the virtual simulation experiment platform.

The normalized path coefficient of H-5 is 0.133 (P=0.034). Therefore, the students' engagement has positive influences on the teachers' guidance. Although such influence is insignificant, it cannot be ignored. In other words, teachers offer more careful and responsible guidance to students who exert more effort and time to the virtual simulation experiment.

The normalized path coefficient of H-6 is 0.325 (P<0.001). Therefore, the teachers' guidance has significant influences on the engagement of students. If teachers propose higher requirements and provide more guidance to students during the virtual simulation experiment course, students will increase attentions to the course and strengthen their learning enthusiasm.

The normalized path coefficient of H-7 is 0.187 (P<0.001). Therefore, the academic basis has significant influences on the students' engagement. This reflects that professional knowledge and simulation experiment knowledge can strengthen their confidence during the experiment. It strengthens the students' engagement to experiment and increase their learning interest to the experiment indirectly.

The normalized path coefficient of H-8 is 0.379 (P<0.001). Therefore, virtual simulation experiment design has significant influences on the students' engagement. In other words, stability and beauty of virtual simulation experiment design, as well as richness of resources, can stimulate the learning interests of students, thus improving their engagement to experiment.

The normalized path coefficient of H-9 is 0.226 (P=0.061). Therefore, virtual simulation experiment design has significant influences on teachers' guiding. Although a virtual simulation experiment can stimulate learning interest of students significantly, teachers would not decrease guidance and plans of experiment due to the use of the simulation experiment platform.

4.4 Path coefficient analysis of observation variables

SEM was tested and calculated by AMOS software, thus gaining the normalized output results of the model. These results are path coefficients of the observation variables (Figure 4).

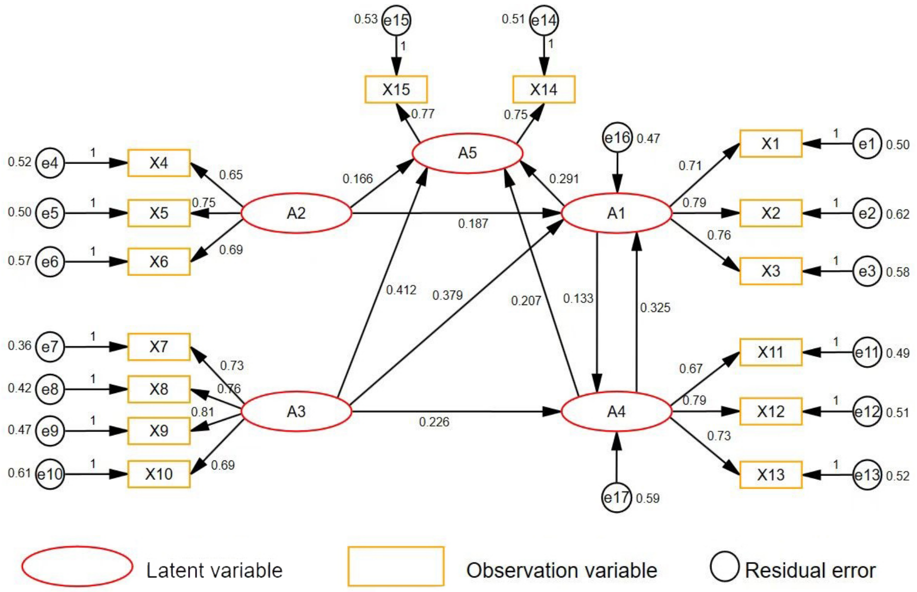

Fig. 4. Acting mechanism of influencing factors

Figure 4 shows that X2 is the observation variable, which influences engagement of students the most, with a path coefficient of 0.79. The path coefficient of X3 is 0.76 and it is the secondary influencing factor of virtual simulation teaching effect in the engagement of students. X1 is the third important influencing factor, with a path coefficient of 0.71.

X5 is the observation variable that influences the academic basis of students the most, with a path coefficient of 0.75. The secondary influencing factor is X6, which has a path coefficient of 0.69. The path coefficient of X4 is 0.65 and is the factor that influences virtual simulation teaching effect the least on academic basis of students.

X9 is the observation variable, which influences the virtual simulation experiment design the most (path coefficient of 0.81). X8 and X7 are the secondary influencing factors of teaching effect in virtual simulation experiment design, with path coefficients of 0.76 and 0.73, respectively. The path coefficient of X10 is 0.69, indicating that X10 is the least important factor of virtual simulation experiment design to teaching effect.

X12 is the observation variable that influences the teachers' guidance the most, with a path coefficient of 0.79. X13 is the secondary influencing factor and its path coefficient is 0.73. X11 is the least important factor of the teachers' guidance to virtual simulation teaching effect and its path coefficient is only 0.67.

5 Conclusion

To recognize influencing factors of virtual simulation experiment teaching effect and the acting mechanism, a conceptual model and a SEM of influencing factors are constructed by the SEM method. Based on the condition and survey data of the virtual simulation experiment, acting path and influencing strength of factors are analyzed. According to path coefficients, virtual simulation experiment design is the primary influencing factor of virtual simulation experiment teaching, followed by engagement of students, teachers' guidance, and academic basis of students successively. Based on the aforementioned results, the following enlightenment can be gained:

(1) Although virtual simulation experiment teaching can stimulate learning interests and initiative of students, it still requires students to equip with some basic professional knowledge and relatively perfect knowledge framework system. Hence, students have to engage in the class fully, track and reflect experimental tasks, summarize through books or network data inquiry, and practice information and knowledge points related with classroom tasks to solidify the content.

(2) In term of influencing strength, teachers' guidance is the least important factor to virtual simulation experiment teaching, but it still has direct influences on teaching effect. Teachers have to strengthen the training of organization ability in the teaching process and accumulate professional knowledge quality to improve teaching effect. Moreover, teachers should optimize the experimental process design reasonably, strengthen students' ability to acquire knowledge positively, and help students in understanding the explicit learning goal, thus assuring the teaching effect of the course.

(3) The virtual simulation experiment design quality has the most significant influences on teaching effect. Therefore, attention should be paid to development and design of experimental projects when using virtual simulation technology into education. Assuring immersion and authenticity of virtual scenes is necessary, which are conducive to knowledge acquisition of students. Moreover, it can use VR technology to stimulate the observation and perception of learners in future simulation experiments, thus making virtual scenes more real. Hence, universities should match and update the simulation experiment timely in accordance with new policies and technologies when building simulation experiment platforms to guarantee that students can contact the leading business knowledge in teaching process and realize a seamless connection with practical posts.

6 Acknowledgment

This study was supported by the Education and Teaching Reform Research and Practice Project of Zhengzhou University of Aeronautics (No. ZHJY22-09).

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Article submitted 2022-07-05. Resubmitted 2022-08-07. Final acceptance 2022-08-09. Final version published as submitted by the authors.