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Research on the Effectiveness of Medical Virtual Simulation Teaching Based on the Factor Analysis Method

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Abstract: Medical education is undergoing a transformation, and virtual simulation (VS) laboratory techniques are increasingly being used to train medical students. In this paper, a questionnaire survey was conducted with 191 medical schoolteachers who have used VS to teach, to investigate the effectiveness of the current implementation of VS in higher education. Factor analysis of the research data was carried out, and two common factors were obtained, namely, "organizational and technological readiness" and "teaching effectiveness and content quality" reflecting the two important factors influencing the effectiveness of VS teaching. It analyses the reasons for the low satisfaction of VS teaching in medical colleges (mean score 3.417) and proposes corresponding countermeasures.

Keywords: Virtual Simulation; Medical Education; Factor Analysis Method; Effectiveness; Satisfaction

1. Introduction

Medical education is undergoing a transformation, with virtual simulation (VS) laboratory techniques increasingly being used to train medical students, which will become more important in the context of time constraints on clinical training and an increased focus on patient safety. Diagnostic errors are a significant source of patient morbidity, and cognitive errors are the most common cause of diagnostic errors. Evidence suggests that most cognitive errors arise from misinterpretation, synthesis and judgement rather than inadequate data collection or knowledge base, and to reduce the incidence of cognitive errors, medical students must experience a wide variety of patient cases [1]. However, the rapid growth of medical information and the expectation of quality healthcare services have increased the complexity of medical decision-making, and as the demand for teaching practice increases, the cost and controllability of teaching resources have all contributed to the difficulty of traditional clinical laboratory teaching in meeting the needs of medical students for a variable and controllable number of experiments and experimental conditions. In recent years, computer screen-based virtual standardized cases (VSP) have been introduced into medical teaching, which is a specific type of computer program that simulates real-life clinical scenarios; learners can simulate the role of a healthcare provider, obtaining a medical history, performing a physical examination, and making diagnostic and treatment decisions [2]. In contrast, VS environments increase the ease and flexibility of experimentation, improve the ability to widely scale and disseminate simulation technology at a lower cost, and with a level of fidelity that can be customized according to learning objectives [3].

VS describes different forms in terms of realism, level of interaction, and presentation (e.g., video or avatar). It includes two categories: extended reality (XR) (immersive) and screen simulation (SS) (non-immersive); XR specifically includes virtual reality (VR), augmented reality (AR), and mixed reality (MR); and screen simulation (non-immersive) includes virtual worlds, virtual games (SGs), and virtual standardized patients (VSPs) [4]. This paper uses the term VS to refer to virtual simulation experiments based on VR, AR, VSP or SG.

There are many variables and design elements that must be considered when applying VS techniques. Teachers must determine in advance the duration, pace, level of realism and standardization, as well as the amount and timing of feedback, coaching or debriefing. These decisions should be aligned with the level of the students and the objectives of the training to help ensure that the training is effective [5].

VS is not the only model that can be used to understand and improve the real world, and there are several reasons for using VS rather than other methods, the main advantages of which are demonstrated:

1.VS Variability. If the modelled system is highly variable, then VS is often the only means of accurately predicting performance. Some systems cannot be modelled analytically [6], and the results obtained by choosing RSE for comparative static analysis are inaccurate because the variability in reality is not taken into account, whereas in VS teaching, the teacher can set up the variability and lead the students to analyze the experimental results under different conditions.

2. Restrictive Assumptions. VS requires almost no assumptions, except for simplified models and assumptions that need to be made when there is a shortage of data. Whereas other modelling approaches require certain assumptions, these restrictions are not appropriate for many healthcare processes. Whereas in VS, any distribution can be chosen [7].

3.Transparency.VS can be more intuitive and different displays of experimental results can be created to give non-specialists a deeper understanding of and confidence in the model [8].

In summary, VS teaching provides students with an effective method of learning practice, allowing them to experience specific knowledge in a controlled environment and to repeat the experiment many times [9]. As a teaching mode that has only emerged in recent years, the use and effectiveness of VS in Chinese medical colleges and universities has yet to be studied, and how to improve the effectiveness of VS teaching is the issue that this paper focuses on.

2. Status Quo

2.1 VS Teaching in China

According to the statistics within the National VS Teaching Project Shared Service Platform, as of September 2023, there are a total of 2,568 VS, while 62 disciplinary categories are set up, such as management, education, art, water conservancy, civil engineering and so on. The largest share is in the management category, with a total of 171 VS, a specific share of 6.7%; the smallest is in astronomy and atmospheric sciences, both of which have 5 experiments, accounting for 2% of the total. There were 1,241 national VS, or 48.3%, and 1,327 provincial VS, or 51.7 %.

The number of VS projects in medicine-related categories, including basic medicine, chemical and pharmaceuticals, clinical medicine, public health and preventive medicine, nursing, pharmacy, biomedical engineering, medical technology, forensic medicine, and psychology, reached 496, or 19.3 per cent of the total (Table 1).

Table 1. Distribution of VS in Medical

Category	VS	per cent(%)
Basic Medical Sciences	98	3.8
Chemical &Pharmaceutical	86	3.3
Clinical Medicine	86	3.3
Public Health and Preventive Medicine	44	1.7
Nursing	40	1.6
pharmacognosy	39	1.5
Chinese medicine	33	1.3
Biomedical Engineering	25	1
Medical technology	23	0.9
Forensic Science	12	0.5
Psychology	10	0.4
Total	496	19.3

Source: https://www.ilab-x.com/

2.2 Questionnaires Analysis

From October 2023 to December 2023, our team made a questionnaire survey to 191 teachers who have used VS teaching in medical schools, the research aims to explore the effectiveness of the current implementation of VS teaching in colleges and universities, and to provide reference for VS teaching into the classroom afterwards. The questionnaire questions were all multiple-choice questions, 22 in total. In the first part, teachers' personal information was collected (10 questions), including the courses they taught, the type of organization they were employed by, and their working hours. In the second section, a Likert scale was designed with questions on satisfaction with teaching support (6 questions), and satisfaction with teaching implementation (6 questions). After the questionnaires were collected, invalid questionnaires were excluded, valid questionnaires were coded and filed, and statistically analyzed using SPSS software.

2.2.1 Statistics of Respondents

According to the region (X_1) where the respondents are located, the majority of them are located in Yunnan, with a high number of 158, and the rest of them are located in Hebei (7), Hubei (5), Fujian (5), Jiangsu (3), Shandong (2), Jilin (2), Liaoning (2), Shanxi (1), Zhejiang (1), Chongqing (1), Shaanxi (1), Shanghai (1), Henan (1), Hunan (1), and Hunan (1).

X_2 is the proportion of the courses taught by the respondents in the institution. X_3 is the type of institution in which the respondents were employed. *X4* is the duration of the respondents' employment in education. The survey data is presented in Table 2.

Table 2. Statistics of Respondents

Varables	Choices	Frequency	%
X_2	postgraduate courses (master's and doctoral degrees)	25	13.089
	undergraduate	133	69.634
	specialized training sudents	61	31.937
X_3	research higher education institutions	36	18.848
	applied higher education institutions	84	43.979
	vocational and skill higher education institutions	63	32.984
	other types of institutions, e.g., part-time teaching, tertiary hospitals, and hospitals affiliated with medical colleges	8	4.188
X_4	≤2 years	69	36.126
	2-5 years (including 5 years)	51	26.702
	5-10 years (including 10 years)	30	15.707
	More than 10 years	41	21.466

2.2.2 VS Teaching and Learning

X_5 is related to types of VS the respondents has used or is using in teaching. X_6 is how the VS paid for according to the respondent's school. X_7 is the students' competencies that the respondents ever used VS want to promote. X_8 is about types of courses in which respondents have used VS. X_9 is that how the respondents prepare students for VS experiences. X_{10} represents the respondents' ways of assessing students' performance in VS. The survey data is presented in Table 3.

Table 3. Statistics of Respondents

Variables	Choices	Frequency	%
X_5	SS	124	64.921
	SG	43	22.513
	AR	45	23.56
	VR	45	23.56
	VSP	44	23.037
X_6	Administration Funding	89	46.597
	Student Paying	41	21.466
	Free	71	37.173
	No Idea	53	27.749
X_7	Problem-solving skills	119	62.304
	Technology and skills development	117	61.257
	Critical hinking	82	42.932
	Leadership	63	32.984
	Interprofessional communication skills	67	35.079
	Capacity to deal with conflict	50	26.178
	Not significant	33	17.277
X_8	Theoretical courses	91	47.644
	Practical courses	121	63.351
	Both types of courses	53	27.749
X_9	Require students to consult relevant resources (readings, videos, other materials) prior to the simulation	130	68.063
	Pre-specification	121	63.351
	Guiding to VS	132	69.11
	Explain the learning outcomes	93	48.691
X_{10}	Student report	107	56.021
	Students' experimental procedure	96	50.262
	Conducting group discussions	95	49.738
	Test	89	46.597
	Evaluate VS for completion	69	36.126
	No assessment conducted	35	18.325

X_{11} is the satisfaction with administrator support for VS teaching. X_{12} is the satisfaction with the support of VS teaching guiding policies enacted by their institution. X_{13} is the satisfaction with developer or vendor support in VS teaching. X_{14} is the satisfaction with teaching preparation in VS teaching. X_{15} is the satisfaction level of students' pedagogical preparation before teaching the proposed simulation experiment. X_{16} is the Satisfaction with VS teaching available to students. X_{17} is the teachers' satisfaction with VS teaching to help students acquire desired knowledge and skills. X_{18} is the teachers' satisfaction with the accuracy of information on VS. X_{19} is the teachers' satisfaction with the VS teaching function. X_{20} is the teachers' satisfaction with VS teaching functions suitable for China's conditions. X_{21} is the teachers' satisfaction with VS multilingualism. X_{22} is the teachers' satisfaction with VS teaching initiative. The results of the survey are presented in Table 4.

Table 4. Statistics of Respondents

Variables	Choices	Frequency	%	Variables	Choices	Frequency	%
X_{11}	1	10	5.236	X_{14}	1	8	4.188
	2	10	5.236		2	22	11.518
	3	75	39.267		3	74	38.743
	4	58	30.366		4	53	27.749
	5	38	19.895		5	34	17.801
X_{12}	1	13	6.806	X_{15}	1	9	4.712
	2	12	6.283		2	8	4.188
	3	72	37.696		3	73	38.22
	4	57	29.843		4	62	32.461
	5	37	19.372		5	39	20.419
X_{13}	1	7	3.665	X_{16}	1	10	5.236
	2	9	4.712		2	20	10.471
	3	67	35.079		3	75	39.267
	4	68	35.602		4	53	27.749
	5	40	20.942		5	33	17.277
X_{17}	1	9	4.712	X20	1	10	5.236
	2	19	9.948		2	19	9.948
	3	85	44.503		3	87	45.55
	4	63	32.984		4	56	29.319
	5	15	7.853		5	19	9.948
X_{18}	1	8	4.188	X21	1	12	6.283
	2	15	7.853		2	19	9.948
	3	84	43.979		3	76	39.791
	4	66	34.555		4	66	34.555
	5	18	9.424		5	18	9.424
X_{19}	1	10	5.236	X22	1	15	7.853
	2	13	6.806		2	23	12.042
	3	77	40.314		3	86	45.026
	4	64	33.508		4	49	25.654
	5	27	14.136		5	18	9.424

3. Factor Analysis

3.1 Validity Analysis

To obtain the main influencing factors affecting teaching satisfaction (X_{11} to X_{22}), 191 questionnaires were factor analyzed. In data analysis for empirical studies, the KMO test (Kaiser-Meyer-Olkin) and Bartlett's test of sphericity are important tools for assessing the suitability of data for multivariate statistical analyses such as factor analysis (Table 5).

Table 5. KMO & Bartlett's Test

KMO		0.905
Bartlett's Test	Approx. Chi-Square	1883.151
	df	66
	P value	0.000***

Note: ***, **, * represent 1 per cent, 5 per cent and 10 per cent significance levels, respectively.

The result of the KMO test was 0.905, a value much higher than the commonly recommended thresholds of 0.5 or 0.6, indicating that the correlation between the variables in the dataset is very strong, making it well suited for factor analyses or other statistical analysis methods that require a high degree of correlation between variables. A high KMO value implies that there is enough common variation among the variables to be effectively grouped into a small number of potential factors, thus simplifying the structure of the data and extracting key information.

The results of Bartlett's test of sphericity also support the conclusion that the data are suitable for factor analysis. The approximate chi-square value of Bartlett's test of sphericity is 1883.151 and the corresponding p-value (level of significance) is 0.000*** (less than 0.001), which indicates the rejection of the null hypothesis of a spherical distribution i.e., that the covariance matrices of the data samples are not unitary matrices but significantly different, i.e. the variables are not completely independent of each other but there is a significant correlation structure. This result further confirms the suitability of the data for factor analysis, which requires some correlation between the variables.

4.2 Total Variance Explained

In exploratory factor analysis, the total variance explained table is the key output for assessing the contribution of each factor to the total variation of the original variables (Table 6; Figure 1).

Table 6 Total Variance Explained

Factor	Eigen Eigen			% of Variance (Rotated)		
	igen Value	% of Variance	Cumulative % of Variance	Eigen Value	% of Variance	Cumulative % of Variance
1	6.423	53.526%	53.526%	4.559	37.988%	37.988%
2	2.62	21.83%	75.356%	4.474	37.284%	75.272%
3	0.532	4.431%	79.788%	0.542	4.516%	79.788%
4	0.417	3.475%	83.262%			
5	0.376	3.133%	86.396%			
6	0.338	2.82%	89.216%			
7	0.321	2.674%	91.889%			
8	0.252	2.104%	93.993%			
9	0.22	1.831%	95.824%			
10	0.196	1.633%	97.457%			
11	0.164	1.371%	98.828%			
12	0.141	1.172%	100%			

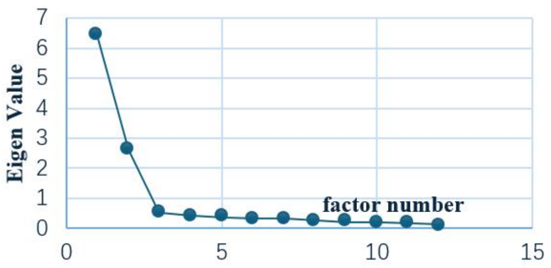

Figure 1. Scree Plot

First, before rotation, the first factor explained 53.526% of the total variance, and the first two factors together explained 75.356% of the variance, indicating that these factors dominated the data structure. However, after rotation, although the cumulative variance explained by the first two factors remained the same, the variance explained by the first factor decreased significantly to 38.033%, reflecting the redistribution of factor loadings by factor rotation, which aimed to improve the interpretability of the factors.

In the results of the exploratory factor analysis, the contribution of the two main components (Component 1 and Component 2) to the examined multidimensional assessment variables of the application of VS in educational organizations can be observed by means of the data from the component matrix table. Component 1 mainly reflects the characteristics of VS in terms of organizational support, readiness for technology application and pedagogical readiness, with high loading values (all greater than 0.2), suggesting that these factors together form a dimension that can be interpreted as 'organizational and technological readiness' (F_1). Specifically, leadership support, instructional policies and processes, the usefulness of the technology, the adequacy of technical support, and the instructional readiness of the teachers are all reflected in this dimension, indicating the fundamental role of these factors for the successful application of VS in educational institutions.

In contrast, component 2 focuses on the characteristics of VS in terms of teaching effectiveness, content quality, applicability and teachers' attitudes, and its loading value is relatively high (all greater than 0.2), and this dimension can be named "teaching effectiveness and content quality" (F_2). The performance of the VS in helping students to achieve the expected learning outcomes, the accuracy of the information, the technical criticality of the features, the adaptability to the Chinese context, the availability of multilingual versions, and the willingness of the teachers to use the VS are all reflected under this dimension. Together, these factors constitute important indicators for assessing the effectiveness of VS in education, emphasizing the importance of content quality and pedagogical adaptability.

5. Conclusion and Recommendations

5.1 Conclusion of the Study

Through the factor analysis of the questionnaire, this paper obtains the organizational and technological readiness(F_1) and teaching effectiveness and content quality(F_2) two factors, reflecting the effectiveness of the current VS teaching of two important factors. Through qualitative and quantitative analyses, it is found that the following problems mainly exist in the low satisfaction of VS teaching in medical colleges and universities (mean score of 3.417).

Lack of adequate funding and school management support. There are two important issues that need to be addressed when adopting VS in education: funding and team support. The administrators usually recognize that the use of technology in the teaching and learning process can sustainably improve the quality of the profession. The role of administrators is to ensure that technology systems are effectively adapted, considering financial, ethical, and legal implications. Technology should reduce the administrative burden on teachers, enabling them to manage their workloads more effectively and provide more time to meet the educational needs of their students.

Project costs affect VS ssustainability. Most VS software is not cheap, and most VS projects take weeks to complete. As a result, both development as well as maintenance costs are high. Therefore, it is important to balance the perspective of the benefits that can be gained from using simulation and schools will only invest in VS projects if the benefits are an order of magnitude higher than the costs.

Insufficient effectiveness of the VS teaching and learning process. Prior to selecting VS for teaching, teachers must ensure that the VS learning objectives are aligned with the course outcomes, and that the integration of VS activities with the learning outcomes will help to ensure the effectiveness of the teaching and learning. To do this, teachers need to be clear about the purpose of VS and the benefits of using it. Students are more motivated to complete an activity when they see a clear link between the learning objectives of the VS and the course objectives. In the survey, some teachers did not grasp the principles of VS teaching and learning, which led to inadequate understanding of the objectives and results of the experiment, thus reducing students' motivation to learn.

5.2 Recommendations

For organizational and technological readiness, it is recommended that the following factors are key considerations when developing or selecting VS, including start-up resources for lab acquisition or customization, content development and maintenance, and data management. There are also administrative needs related to login information, training, and performance tracking. In addition, teachers may need specialized training to operate and implement VS effectively. although the incorporation of VS into teaching and learning is intended to be a low-cost, easily accessible technology solution. Teachers often encounter IT barriers such as firewalls. A learning management system that can be incorporated into the VS curriculum would help to address this issue. The rapidly changing VS technology is a major challenge in establishing VS courses. To address duplication, the state should introduce standards for medical VS as soon as possible, which would reduce the need for ongoing training of content developers and students in new formats. In addition, National VS Teaching Project Shared Service Platform should share more VS resources and ensure their use.

With respect to teaching effectiveness and content quality, higher education should determine whether VS achieves the same educational outcomes as traditional methods, as measured by learning efficiency, theory testing, skills testing, and other educational outcomes. VS must also be assessed in relation to traditional educational methods, and it must be determined whether VS results in a more cost-effective education. Ideally, VS should be able to demonstrate the same validity and reliability as current assessments, and further development of methods for assessing the quality and effectiveness of VS teaching and learning is a priority for future medical teaching research.

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