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The development and practice of STEM curricula under the integration of virtual simulation in the context of new-era education reform and innovation

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Abstract: STEM teaching, which differs from traditional concepts, combines knowledge and abilities to cultivate innovative talents, aligning with China's new education reform. The rise of localized STEM teaching and the use of emerging technologies like virtual simulation are guiding its research direction. This paper explores new approaches to STEM education reform through virtual simulation technology, designing a teaching model with elements like objectives, procedures, tools, resources, evaluation methods, and the roles of teachers and students. Through teaching training, it explores virtual simulation teaching resources and methods, aiming to empower the cultivation of innovative talents with new technologies.

Key words: STEM teaching; virtual simulation; curriculum development; creative thinking

1 Introduction

The rise of localized STEM education is being driven by emerging technologies. In 2019, the Ministry of Education endorsed the use of low-risk technologies like augmented and virtual reality in teaching [1]. This led to the development of top-tier undergraduate courses related to virtual simulation. The integration of these technologies into teaching methods is now a trend. The "Twenty Major Measures" initiative emphasizes the construction of new educational infrastructure and data-driven governance models, which include improving educational information standards, developing a national smart education platform, and innovating teaching models [2].

Therefore, this article explores how university teachers integrate virtual simulation technology into STEM education, promote its long-term development, and empower talent innovation.

2 STEM education and theoretical research on virtual simulation teaching

2.1 Definition of core concepts

2.1.1 STEM teaching literacy

China National Academy of Educational Sciences identifies STEM teachers as professionals integrating interdisciplinary teaching. This study focuses on teachers in primary and secondary schools involved in STEM teaching [3].

STEM teacher literacy aligns with teachers' personal qualities, behaviors, and STEM educational concepts. Personals literacy, including attitudes, values, and moral cultivation, significantly influences STEM teaching methods, making it a fundamental part of STEM teacher literacy.

Global STEM teacher competency standards highlight teaching practice ability, forming the core of STEM teacher literacy, known as professional literacy. However, STEM teacher literacy also emphasizes process attributes, reflecting the transformation of STEM teachers from novices to professionals, involving adaptation to environmental changes and continuous literacy improvement.

2.1.2 Virtual simulation teaching

Since Professor Wolf introduced virtual experiments in 1989, the field has expanded globally, with applications in scientific research, industrial manufacturing, and higher education [4]. Virtual and simulation technology in experimental teaching addresses global challenges and enhances students' practical skills.

Virtual simulation and experimental teaching are core parts of higher education's digital transformation. By integrating information and intelligent technology, it solves multiple problems in experimental teaching, especially in science and engineering colleges, advancing from "Internet+ education" to "Intelligence+ education".

By the end of 2020, universities launched 2,079 virtual simulation experiment teaching projects through the "iLAB" platform, with 728 projects receiving national recognition. These achievements mark a significant milestone in China's higher education virtual simulation experiment teaching [5].

2.2 Construction of STEM and virtual simulation teaching modes

2.2.1 Construction of STEM teaching mode

The STEM teaching mode mainly includes theoretical foundation, teaching objectives, teaching procedures, operating conditions, and teaching evaluation. Based on a student perspective, it includes discovering problems, proposing hypotheses, scientific verification, drawing conclusions, reflecting and sharing, and progressing step by step to achieve a closed-loop structure.

2.2.2 Virtual simulation experiment teaching mode

The virtual simulation experiment teaching mode comprises the mixed reality experimental inquiry teaching mode and the VR all-in-one machine teaching design mode, and this study mainly uses the latter to conduct research, as specifically illustrated below:

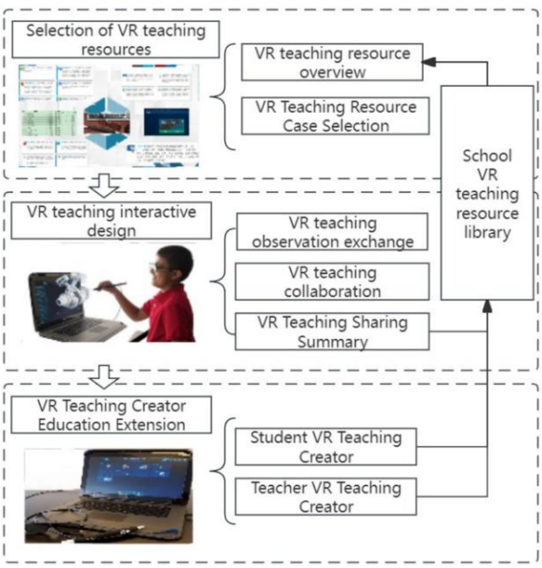

Fig. 1. VR all-in-one machine teaching design mode

The VR all-in-one machine teaching design mode involves surveying the teaching resource library, selecting resource cases, designing interactive teaching, and facilitating educational extension. It also includes feedback on VR teaching sharing, summarizing, and educational creation to improve the teaching resource allocation in the VR teaching resource library [6].

3 Research design and methods

3.1 Research object

This study included 20 volunteer teacher candidates from College of Education, Hangzhou Normal University. Three teaching experiments were conducted in teaching and control classes with equivalent knowledge levels. A STEM literacy level test was administered before the experiment to ensure no significant differences. The proportions of professional classification and gender distribution were balanced to minimize other factors' influence.

3.2 Research design

3.2.1 Implementation process

The teaching and training course consists of three sessions. The first session introduces students STEM teaching content and virtual simulation technology, focusing on designing a protective suit for STEM inquiry teaching with augmented reality. The second session familiarizes students with STEM teaching elements and the virtual simulation equipment resource library. In the third session, students integrate virtual simulation and STEM knowledge to discuss and research design tasks.

3.2.2 Data collection tools

① Classroom teaching

The study used multifunctional devices to capture and record the teaching process of each class, including teacher behavior, student participation, and relevant data. This data is valuable for analyzing student performance, identifying teaching issues, and supporting the research findings.

② Questionnaire

The questionnaire for the STEM pre-test literacy of normal college students includes personal information such as gender, major, and grade, which helps understand the basic situation of the participants and analyze differences based on gender, major, and grade. It improves the accuracy of the survey analysis in this study.

Table 1. Part of the questionnaire for the pre-test of STEM literacy for Normal University

	Test questions	Completely true	Basically true	True	Not true	Completely not true
Teaching design	1. I understand the basic knowledge of STEM.					
	2. I can effectively correlate STEM knowledge with other disciplines for instructional design.					
	3. When I design teaching, I can focus on students' STEM literacy, and the design of teaching objectives covers students' knowledge, behavior, higher-order thinking, and other fields.					
	4. I can choose appropriate life scenarios for teaching.					

The "Virtual Simulation Experiment Effect Test Scale" in this study is designed to measure three key aspects: immersion, interaction, and creativity.

Table 2. Part of the virtual simulation experiment effect test scale

		Consciousness immersion (comprehension)
		Consciousness immersion (Applied)
	Flow experience	My attention was completely focused on what I was doing.
		During the event, time seems to slow down or speed up.
		I feel that I am capable enough to cope with the high demands of teaching activities.
		I felt good about this learning experience.
Interactivity	Social interaction	I was able to participate in virtual simulations with other students
		I was able to get help from others when I was doing virtual simulations
	Environment interactions	How easy it is to interoperate
		The depth of the hierarchy of interactions
Creativity	Information processing	Knowledge assimilation: I can integrate what I already know when conducting virtual simulation experiments
		Knowledge adaptation: I was able to learn something new while conducting virtual simulation experiments
	Cognitive development	Assimilated knowledge meaning learning: Provide information that has been learned and needs to be reconstructed
		Learning by the meaning of knowledge: Provide information that needs to be reconstructed without understanding

4 Analysis of research results

4.1 STEM literacy assessment

Based on the pre-test, the researchers implemented the teaching. After implementation, students' STEM literacy was tested, and the results of the test were matched with the experimentally treated STEM literacy test results of the matched T sample, as shown in the table. The average difference between the previous and subsequent tests of STEM creative consciousness is -1,62952, suggesting that the reform model of STEM teaching methods, including virtual simulation technology, can improve the STEM literacy of students and teachers.

Table 3. Paired sample t-tests for pre- and post-tests of pre-service STEM literacy for teachers

Test items	Pairing difference					t	Degree of freedom	Say. (Futao)
	Average value	Standard deviation	Standard error average value	Difference 95% confidence interval				
				Lower limit	Upper limit			
STEM teaching literacy pretest - STEM teaching literacy post-test	-1.62952	2.42560	.54238	-2.76474	-.49430	-9.164	19	.000

Instructional design pre-test - Instructional design post-test	-.70952	.73583	.16454	-1.05390	-.36514	-4.312	19	.000
Pre-test for teaching implementation - post-test of teaching implementation	-.52000	.91858	.20540	-.94991	-.09009	-2.532	19	.020
Teaching reflection and reform pre-test - pedagogical reflection and post-test of reform	-.40000	.77119	.17244	-.76093	-.03907	-2.320	19	.032

The third-course training content of this experiment is to make students design a space suit and have three classmates who have never received STEM teaching training conduct a multidimensional evaluation of the design. The score scale selected is the "STEM Literacy Assessment Scale Based on Creative Performance". Finally, three sets of different score data were obtained, and a multidimensional analysis was conducted based on the interview results.

Table 4. Based on the assessment of STEM literacy linked to creativity (partial)

Scoring dimensions					Average horizontal
Problem identification	Problem-solving	Interdisciplinary competence	Ability to innovate	Ability to work together	77.2%
78%	75%	79%	81%	73%	

Based on the displayed scoring situation, the total scores given by the three evaluators are 42.3, 41.3, and 43.65. Among them, the three evaluators gave higher evaluations in the aspects of problem identification ability, interdisciplinary ability, and innovation ability of the presented works, which is consistent with the student performance and self-feedback in the STEM classroom learning activities.

From the overall score rate of the task sheet outcome in Table 4, the final score rate of each participant in the "problem identification" dimension is 78%, in the "problem-solving" dimension is 75%, in the "interdisciplinary ability" dimension is 79%, in the "innovation ability" dimension is 81%, and in the "collaboration ability" dimension is 73%. Based on the discussion of average score rates by scholars, the results indicate that the overall creativity performance of the participants is considered "good".

Table 5. Based on the creativity performance, the STEM literacy score rate (part)

Scoring dimensions		Grade student 1	Grade student 2	Grade student 3	Subtotal
Problem identification capabilities	Contextual requirements	3.4500	3.4500	3.8000	10.7
	Build imagination and creativity	3.8000	3.6500	3.7500	11.2
	Not limited to a single discipline	3.7500	3.4000	3.7000	10.85
Problem-solving skills	Focus on traditional solutions to deficiencies	3.3000	3.5000	3.4500	10.25
	Be clear about how you can improve	3.3500	3.2500	3.5000	10.1
Interdisciplinary competence	Provide new ideas for learning in other disciplines	3.8000	3.5500	3.8500	11.2
	Provide STEM learning methods	3.5000	3.4000	3.4500	10.35
Ability to innovate	Replace existing ways with new ones	3.1500	3.2000	3.4500	9.8
	Extensions based on existing models	3.7000	3.6500	3.7500	11.1
	A completely new concept	3.9000	3.4000	3.9000	11.2
Ability to work together	Adequate in-group discussions	3.1500	3.4000	3.2500	9.8
	Members are actively involved	3.4500	3.4500	3.8000	10.7
Score		42.3	41.3	43.65	127.25

4.2 Evaluation of the integration effect of virtual simulation in STEM teaching

The interviews revealed that the integration of virtual simulation technology primarily impacts STEM multi-sensory perception, teaching interaction, and creativity.

4.2.1 The impact of the sensory immersion of virtual simulation on multi-sensory perception in STEM teaching

Based on the three-phase teaching interviews, virtual simulation technology has a positive impact on multi-sensory perception, psychological immersion, and flow experience. The VR teaching resources on the zSpace all-in-one machine provide sensory experiences and attract attention through stereo display effects and diverse audiovisual experiences. This enhances sensory stimulation in STEM teaching.

Virtual simulation experiments immerse students' senses and enhance their learning experience by focusing their attention. Compared to traditional didactic approaches, virtual simulation technology stimulates cognitive processes through multisensory stimulation, thereby improving the learning effectiveness of STEM teaching: "In the virtual laboratory we encountered, teachers can use images, videos, and other means to show the entire process to students, which can stimulate students' interest in learning and improve students' learning efficiency" (STU-15: the 15th respondent of the experiment).

Additionally, the sensory immersion of virtual simulation technology may lead to information overload, exceeding students' processing capacity and affecting their understanding of STEM knowledge.

4.2.2 The impact of interactive virtual simulation on STEM teaching interaction

Virtual simulation technology enables social and environmental interaction in STEM teaching. Participants can engage in collaborative virtual simulations and complete teaching tasks together. They can also experience the difficulty level and depth of interaction with the teaching equipment.

During teaching, students can experience the authenticity of the equipment and feel a sense of achievement in the interactive environment. However, limitations in the flexibility and speed of operation feedback have been observed. Therefore, the design of virtual simulation experiments should focus on enhancing the experiential sense of equipment interaction.

Next, creating an interactive environment for teamwork is essential in STEM teaching. Virtual simulation scenes facilitate cooperation and interaction between teachers and students. Cooperative communication and problem exploration promote deep learning, attention focus, and teamwork: "We need teamwork to design experiments and analyze data. At the same time, teamwork can also enhance our collaborative and communicative abilities." (STU-18)

4.2.3 The influence of conceptual consciousness of virtual simulation on creativity cultivation

During the integration of virtual simulation technology into the context, sessions, and issues of STEM instruction, students can continue to explore and process information and knowledge, and based on this, realize the construction and creation of knowledge, which can cultivate students' problem-solving abilities and innovative thinking. Meanwhile, creativity is further cultivated in this process, "Virtual simulation technology can also provide students with more opportunities for independent learning, enabling independent exploration and thinking in virtual classrooms, and enhancing independent learning and creative abilities." (STU-20)

Furthermore, based on virtual simulation technology, the operation requirements for certain skills and equipment may be too cumbersome or opaque, which may create feelings of frustration and impact the expression of creativity.

5 Research conclusion and prospect

This research explores the integration of virtual simulation technology in STEM teaching and its impact on learning outcomes. The study aims to enhance multi-perception, teaching interaction, and creativity in STEM education. However, further research is needed to improve the model due to limitations in time, cost, and resources.

The proposed "virtual simulation + STEM" teaching model considers the main processes of STEM education and virtual simulation experiment characteristics. Future research should explore variables such as teacher's teaching background, personality traits, and teaching habits to better understand the impact of virtual simulation on their teaching ability.

The scale design used in the research requires improvement. Further investigation and evaluations are necessary to address the subjectivity of scale items and improve their quality in the specific virtual simulation context.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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