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RESEARCH

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Application of the online teaching model based on BOPPPS virtual simulation platform in preventive medicine undergraduate experiment

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Abstract

Background As online teaching gains prevalence in higher education, traditional face-to-face methods are encountering limitations in meeting the demands of medical ethics, the availability of experimental resources, and essential experimental conditions. Consequently, under the guidance of the BOPPPS (bridge-in, objective, preassessment, participatory learning, postassessment, summary) teaching model, the application of virtual simulation platform has become a new trend. The purpose of this study is to explore the effect of BOPPPS combined with virtual simulation experimental teaching on students' scores and the evaluation of students' participation, performance and teachers' self-efficacy in preventive medicine experiment.

Methods Students from Class 1 and Class 2 of 2019 preventive medicine major in Binzhou Medical University were selected as the research objects. The experimental group (class 2) ($n=51$) received the teaching mode combined with BOPPPS and virtual simulation platform, while the control group (class 1) ($n=49$) received the traditional experimental teaching method. After class, the experimental report scores, virtual simulation scores, students' engagement scale (SES), Biggs questionnaires, and teachers' sense of self-efficacy (TSES) questionnaires were analyzed.

Results The experimental report results demonstrated a significant increase in the total score of the experimental group and the scores of each of the four individual experiments compared to the control group ($P<0.05$). To investigate the impact of the new teaching model on students' learning attitudes and patterns, as well as to evaluate teachers' self-efficacy, a questionnaire survey was administered following the course. The SES results showed that students in the experimental group had high performance scores on the two dimensions of learning methods and learning emotions ($t=2.476$, $t=2.177$; $P=0.015$, $P=0.032$). Furthermore, in the Biggs questionnaire, the total deep learning score of the experimental group was higher than that of the control group ($t=2.553$, $P=0.012$), and the deep learning motivation score of the experimental group was higher than that of the control group ($t=2.598$, $P=0.011$).

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The TSES questionnaire shows that most teachers think it is easier to manage students and the classroom and easier to implement teaching strategies under this mode.

Conclusions The combination of BOPPPS and the virtual simulation platform effectively enhances the experimental environment for students, thereby improving their academic performance, engagement and learning approach in preventive medicine laboratory courses.

Keywords BOPPPS model, Virtual simulation platform, Preventive medicine, Experimental teaching implementation, Experimental teaching evaluation

Introduction

Preventive medicine is a discipline that studies the relationship between external environmental factors and human health. It is a highly practical and applied discipline [1]. Experimental teaching is an important part of preventive medicine teaching and plays an important role in the training of public health talents [2]. Traditional laboratory teaching methods have long been the cornerstone of undergraduate preventive medicine education. While these methods are effective in many respects, they encounter significant limitations when applied to experiments involving hazardous chemicals and biological agents. Such experiments often cannot be conducted in a laboratory setting due to safety and ethical concerns. Addressing these challenges will require exploring alternative approaches and refining existing methodologies [3, 4]. Therefore, there is an urgent need for a novel pedagogical model to enhance the experimental teaching of preventive medicine. This model should aim to significantly improve instructional quality, foster student engagement, and promote autonomous learning capabilities.

The utilization of virtual simulation experiment teaching represents a novel pedagogical approach that effectively addresses the limitations associated with traditional experimental teaching methods [5]. This teaching model is a visual experimental operating environment constructed by using computer and virtual reality (VR) technology to simulate experiments by operating computers. It breaks through the limitations of time, region and experimental resources, and achieves the teaching effect that traditional experiments cannot achieve. Therefore, it has been widely used in practical teaching [4]. Recent research indicates that virtual simulation can effectively improve students' academic performance, fosters students' intrinsic motivation and satisfaction while underscoring the practical application of foundational knowledge, can significantly enhance student engagement [6–8]. Nevertheless, it is not without its limitations and shortcomings, including an absence of clearly defined learning objectives and effective interaction, and students are still in a passive learning approach. BOPPPS, or instructor-learner interaction teaching model, was proposed by Douglas Cole of the University of British Columbia as a goal-oriented and student-centered teaching method. This model consists of six interconnected phases: bridge-in (B), objective (O), preassessment (P), participatory learning (P), postassessment (P), and summary (S). These elements are closely linked to teaching activities, forming a comprehensive closed-loop teaching unit [9–12]. In recent years, this model has been increasingly adopted in medical education, resulting in commendable teaching outcomes [9]. The research findings demonstrate that this model effectively integrates teaching content with instructional methods, enabling educators to systematically organize the teaching process. It enhances interactive communication and feedback between teachers and students and activates students' subjective initiative in learning. This approach addresses the limitations of virtual simulation teaching, thereby improving the overall effectiveness of the educational experience [6, 12, 13]. In educational reform, the Students' Engagement Scale (SES), the Biggs Questionnaire (Biggs), and the Teachers' Sense of Students' Engagement Scale (TSES) are commonly used to assess the effectiveness and indispensability of instructional approaches. These tools have also been instrumental in enhancing the BOPPPS teaching model by evaluating student engagement, learning strategies, and pedagogical outcomes [14].

BOPPPS and virtual simulation platforms have individually been implemented in the teaching of medical specialties with positive outcomes [10, 15]. However, combination use is rare. Therefore, this study integrates the BOPPPS teaching model with a virtual simulation platform to evaluate its effects on students' achievement, engagement, learning approaches and teachers' self-efficacy in preventive medicine experiments, as assessed through experimental reports and questionnaire results. The aim is to enhance the learning experience in preventive medicine laboratories, ignite students' passion and curiosity, and foster their ability to integrate theory with practical application.

Methods

Participants

The participants were 100 undergraduates of preventive medicine in Binzhou Medical University, class 2019. They were randomly divided into two groups according to class. There were no statistically significant differences in gender, learning interest attitude, and previous academic performance between the two groups ($P>0.05$). Among them, the control group (Class 1) comprised 49 students who received traditional experimental teaching methods, while the experimental group (Class 2) consisted of 51 students who were exposed to the new experimental teaching model of BOPPPS combined with a virtual simulation platform. All participants have informed consent to the content of this study.

Design

In this study, four experiments that meet the requirements of virtual simulation experiment were selected from six experiments for teaching reform. Both the experimental group and the control group carried out four experimental teaching (OPI, SPI, BFS, FCD), and the course hours were arranged for 3 class hours.

The control group was taught by traditional experimental teaching methods. Before class, the teacher forwarded the learning objective, learning focus, and accompanying learning materials to the students based on the lesson content. And students previewed before class according to the above content. In class, the teacher initially presented the primary learning objectives and content of the lesson, utilizing instructional videos related to the experiment to enhance students' comprehension. The students took notes as they listened. After the video ended, the teacher used a PowerPoint presentation to display case studies and related questions regarding the experiment, followed by group discussions among students. Subsequently, both the teacher and students engaged in an in-depth analysis of the case. Finally, the teacher summarize the key points and precautions of this experiment course. After class, the students completed their experiment reports, which the teacher then corrected and provided feedback on.

The experimental group adopted virtual simulation teaching based on BOPPPS. The BOPPPS-Virtual simulation platform flowchart is summarized in Fig. 1. Before class, the same procedure was used for the experimental and control groups, except that the experimental group was given relevant experimental focus and materials according to the new instructional design. During the class, the BOPPPS teaching model is structured into six distinct components. Bridge-in (B): The teacher played relevant videos according to the course content to stimulate students' interest. Through this visual medium, students acquire a comprehensive understanding of the experiment's contextual background. Objective (O): The teacher defined the important and difficult points of this experiment course according to the teaching syllabus and presents them to the students in the form of courseware. Preassessment (P): By asking students about the experimental knowledge in this section, we can understand the degree of mastery of experimental knowledge by students before class. Participatory learning (P): Participatory learning allowed students to engage in the learning process, positioning them as the core participants. Using a virtual simulation experiment platform, students completed a series of experiments, namely Organophosphate poisoning (OPI), solanine poisoning (SPI), bulk food sampling (BFS) and formaldehyde content determination (FCD). The virtual simulation platform had multiple virtual places built in, and each place simulated different public health events (Fig. 2). After mastering the basic

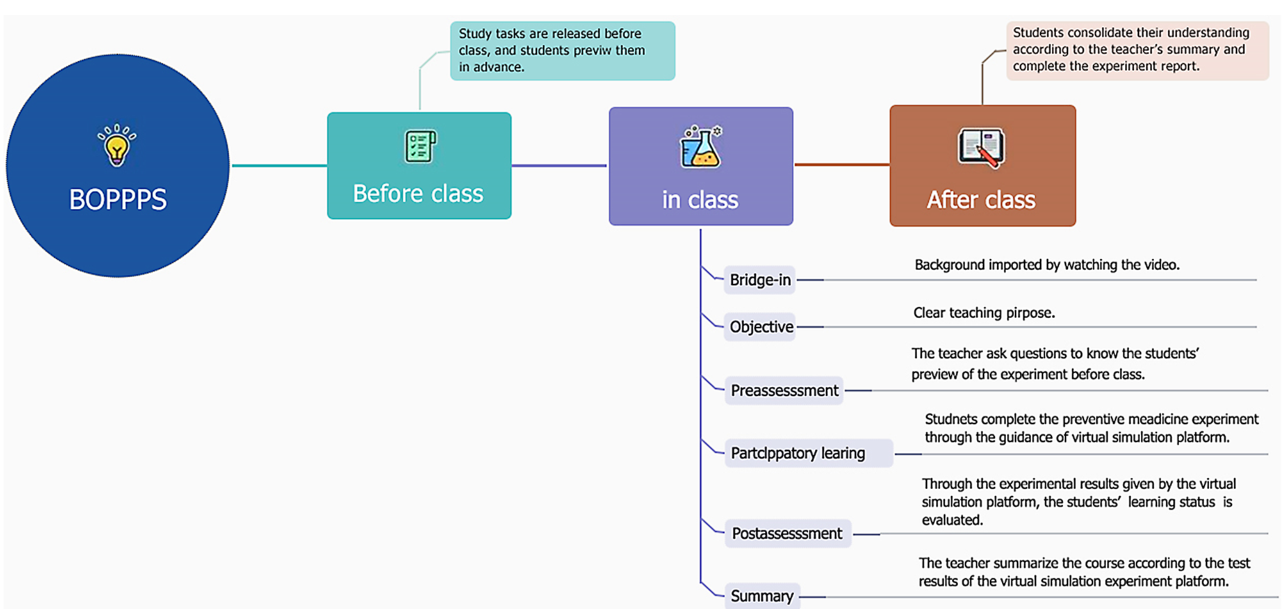

Fig. 1 Example of class design for the BOPPPS model

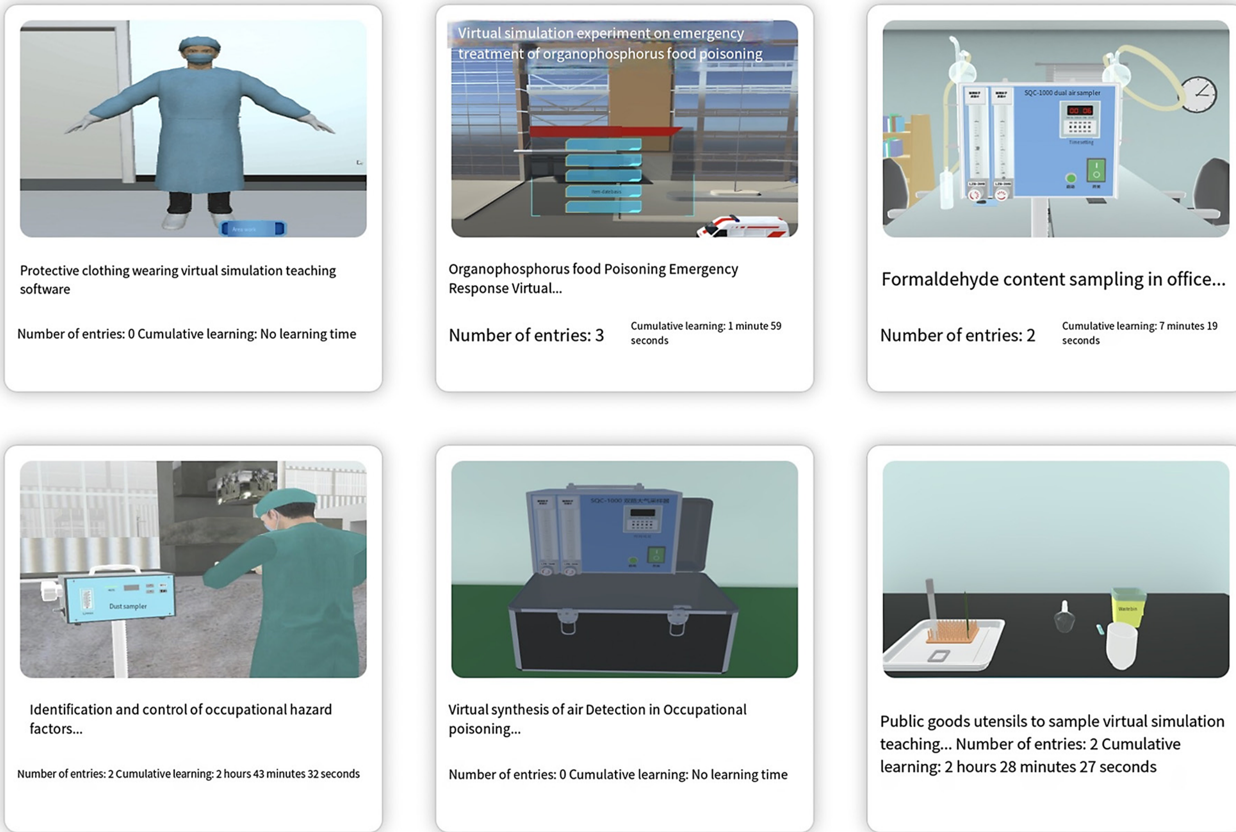

Fig. 2 Virtual simulation experiment of preventive medicine

knowledge, students selected the scene related to the experiment in this section according to the course content and complete the experiment process by following the system prompts on the computer. Taking the case of food poisoning as an example (Fig. 3), the platform adopted the form of 3D real scene simulation to model the real event as the background. The scene began with a briefing describing the background of the patient's food poisoning. Subsequently, the user could interact with the virtual patient through the dialogue, asking about the previous dietary history and looking for the cause of food poisoning. The physiological parameters of the patients were monitored, and the patients were observed and treated. Immediately after the simulation, the platform presented an accident cause interface. Moreover, the simulation report was given to inform the correct cause of food poisoning. So that students can understand the correct process. Postassessment (P): After the completion of the experiment on the virtual simulation experiment platform, the platform formed operational scores. This was the result of the postassessment. Summary (S): Finally, the teacher made a specific summary of this experiment class according to the operation scores of the virtual simulation platform and helped them to establish a thorough knowledge framework. After class, the students proceeded to consolidate their understanding in alignment with the teacher' s summary, while concurrently finalizing the experimental report. Moreover, the teacher gives feedback to the students according to the results of experiment report.

Effectiveness assessment

At the conclusion of the course, the effectiveness and satisfaction of the two different teaching methods were evaluated based on scores from experimental reports, virtual simulation platform tests of the experimental group, and the results of three distinct questionnaire surveys. These questionnaires were distributed by the instructor via the "Dui Fen Yi" WeChat public account.

Student learning

Experimental report scores: Both the experimental group and the control group were evaluated using the same experimental report. The results of the experimental report consisted of four scores: OPI, SPI, BFS, and FCD. Each test was graded on a 100-point scale.

Virtual simulation platform test scores of the experimental group: The results of the virtual simulation platform were composed of four test scores. Respectively, there were OPI, SPI, BFS, and FCD. Each examination

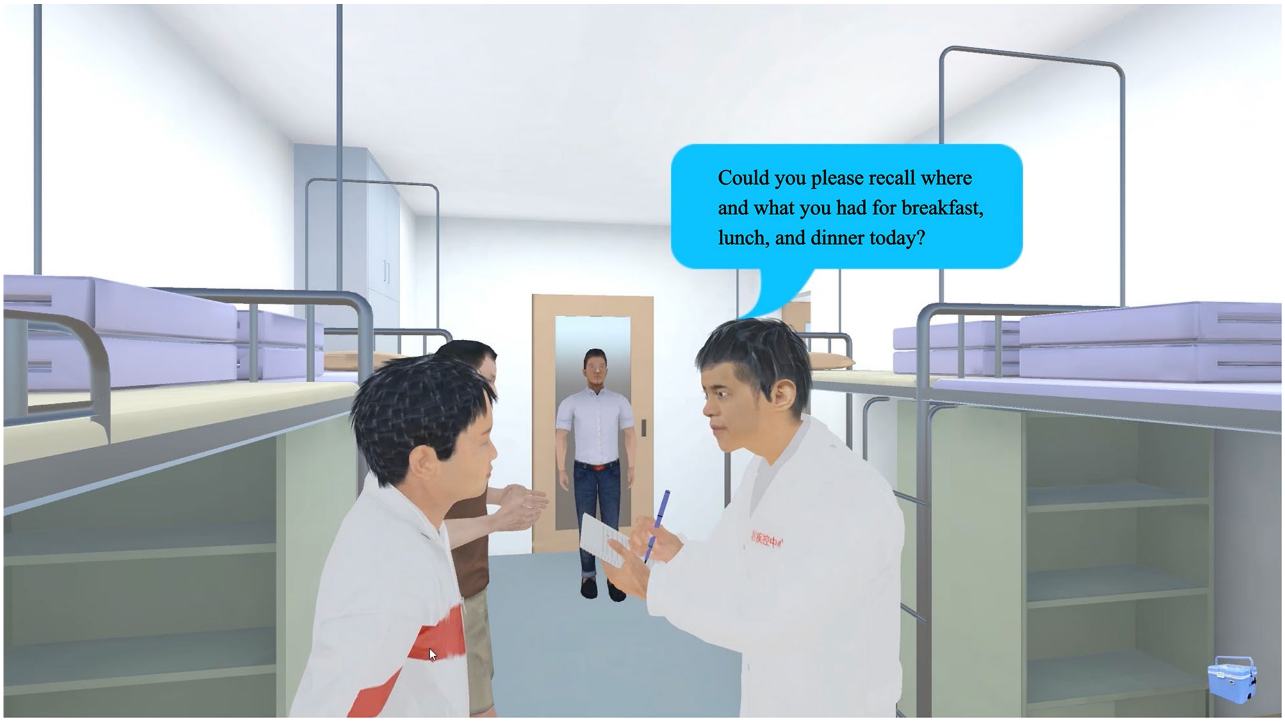

Fig. 3 Virtual simulation experiment of "food poisoning"

was based on a 100-mark system. The total score was the average of the four experimental scores.

Student engagement

The Students' engagement scale (SES) questionnaire mainly involves four aspects: learning method, emotions, participation and manifestation [16]. Each dimension contains different test items, so as to better understand the students' learning situation. Five-point Likert scales were used to evaluate the questionnaire variables. The scoring options were 1=not at all like me, 2=not quite like me, 3=not sure, 4=like me, 5=very much like me, the Cronbach alpha coefficient in this study was 0.816–0.871.

Learning approach

The Biggs questionnaire delves into both deep and shallow learning approaches [17], encompassing various learning strategies and motivations within each approaches. The scoring options available were: 1=never, 2=sometimes, 3=half of each, 4=often, 5=always. The Cronbach alpha coefficient in this study was 0.747–0.892.

Teacher self-efficacy

The Teachers' Sense of Self-Efficacy (TSES) questionnaire includes three aspects: student management, teaching strategy implementation and classroom management. Each dimension contains different test items, which is an effective tool to evaluate teachers' feedback on teaching efficacy. According to the feedback, the score is 1–5 points. The scoring options available were: 1=completely impossible, 2=almost impossible, 3=able to do a little, 4=basically able, 5=completely achievable. Cronbach' s alpha coefficient in this study was 0.711–0.862.

Statistical analysis

The SPSS version 26.0 software was used for data analysis. The measurement data were expressed as mean±standard deviation($\bar{x}\pm s$), and the independent sample *t*-test was used to compare between different groups. Counting data are expressed in frequency and percentage, using the χ^2 test to compare the percentage of people with 4 points or more. The total scores of both the experimental report and the virtual simulation platform test are derived from the percentage-based evaluation of four experimental results. Due to the non-normal distribution of the experimental report scores, a statistical description was employed using the median (interquartile range), M (*P*25,*P*75), and a non-parametric rank sum test was utilized for group comparisons. Test level a = 0.05.

Results

Student Learning

Experimental report scores

Table 1 presents an analysis of the experimental report scores for the experimental and control groups. The total score for the experimental group 382.00 (377.00, 386.67)

Table 1 Experimental report scores

	Experimental group	Control group	z-value	*P*-value
Bulk food sampling	96.00(93.00,100.00)	90.00(90.00,95.00)	4.421	0.001
Solanine poisoning	93.00(91.00,93.33)	90.00(85.00,92.00)	3.272	0.001
Organophosphate poisoning	98.00(95.00,100.00)	97.00(90.00,98.50)	2.123	0.034
Formaldehyde content determination	100.00(96.00,100.00)	95.00(90.00,98.00)	4.988	0.001
Total scores	382.00(377.00,386.67)	374.00(360.00,379.00)	5.311	0.001

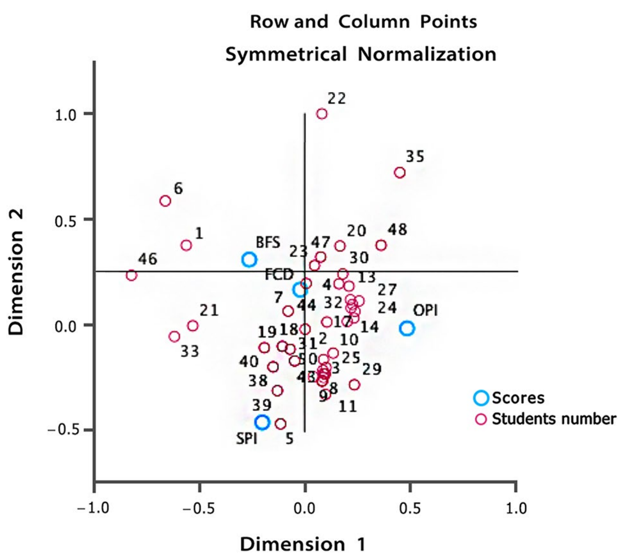

Fig. 4 Correspondence analysis result

was significantly higher than that of the control group 374.00 (360.00, 379.00) (z=5.311, P=0.001). Furthermore, the scores for each of the four individual experiments were significantly higher in the experimental group compared to the control group (P<0.05).

Virtual simulation platform test scores of the experimental group.

The correspondence analysis was made between the Student IDs and the four scores of the experimental group students. The results of the correspondence analysis show that the students in the second quadrant have better BFS scores, but fewer students; students in the third quadrant have better SPI scores; students in the fourth quadrant have better OPI scores, and the number of students is relatively large, indicating that students are relatively good at OPI operation. Therefore, it is necessary to strengthen students' operation ability and experimental knowledge of FCD and BFS experiments to improve their performance (Fig. 4).

Questionnaire result

Both groups of students and teachers participated in the survey and completed the questionnaire. Notably, the questionnaire recovery rate and effective rate were both 100%.

As shown in SES, statistical analysis revealed that the learning methods and learning emotions scores of the students in the experimental group was higher than that of the control group (t=2.476, t=2.177; P=0.015, P=0.032) (Table 2). On the learning method dimension, students in the experimental group demonstrated greater effectiveness in pre-learning before class (3.294±0.923) and keep learning (3.765±0.790) compared to the control group (P=0.002; P=0.022); In terms of learning emotion, the experimental group scored higher than the control group in doing their best to learn (4.098±0.671), finding ways to maintain interested in the course (3.941±0.732), and really wanting to learn (3.628±0.871) (Table 3). The above results showed that the students in the experimental group had better learning enthusiasm and learning situation under the new teaching model.

The results of Biggs showed that the total score of deep learning (33.04±6.190) and the score of deep learning motivation (16.47±3.645) in the experimental group were higher than those in the control group

Table 2 Results of questionnaire survey

Questionnaire	Project	Experimental group	Control group	t-value	*P*-value
SES	Learning method	22.22 ± 3.657	20.45 ± 3.471	2.476	0.015
	Emotion	18.75 ± 3.039	17.42 ± 3.007	2.177	0.032
	Participation	20.08 ± 4.625	19.61 ± 3.696	0.555	0.580
	Manifestation	6.76 ± 1.607	6.78 ± 1.311	-0.037	0.971
	Total scores	67.80 ± 10.74	64.27 ± 8.507	1.822	0.072
Biggs	Deep learning motivation	16.47 ± 3.645	14.69 ± 3.177	2.598	0.011
	Deep learning strategies	16.57 ± 3.390	15.41 ± 2.738	1.879	0.063
	Total deep learning score	33.04 ± 6.190	30.10 ± 5.253	2.553	0.012
	Shallow learning motivation	11.63 ± 4.113	12.65 ± 2.658	-1.487	0.141
	Shallow learning strategies	12.24 ± 4.136	12.69 ± 2.671	-0.661	0.510
	Total shallow learning score	23.86 ± 7.621	25.35 ± 4.626	-1.182	0.240

Table 3 Results of SES questionnaire

Project	Score 4 and above n(%)			Scores		
	Experimental group	Control group	P-value	Experimental group	Control group	P-value
Learning method						
Pre-learning before class	22(43.14)	13(26.53)	0.082	3.294 ± 0.923	2.694 ± 0.962	0.002
Keep learning	34(66.67)	32(65.31)	0.886	3.765 ± 0.790	3.286 ± 1.208	0.022
Review after class	37(72.55)	34(69.39)	0.728	3.863 ± 0.800	3.612 ± 0.909	0.146
Planned learning	34(66.67)	30(61.22)	0.571	3.628 ± 0.848	3.571 ± 0.764	0.730
Listen carefully	36(70.59)	31(63.27)	0.436	3.765 ± 0.790	3.551 ± 1.022	0.244
Take good notes	42(82.35)	35(71.43)	0.194	3.902 ± 0.900	3.735 ± 0.908	0.357
Emotion						
Do your best	46(90.20)	40(81.63)	0.217	4.098 ± 0.671	3.796 ± 0.735	0.034
Theory and practice	27(52.94)	28(57.14)	0.673	3.588 ± 0.876	3.551 ± 0.937	0.838
Practical application of what you learn	25(49.02)	26(53.06)	0.686	3.490 ± 0.809	3.449 ± 0.937	0.814
Maintaining interest in course	38(74.51)	32(65.31)	0.315	3.941 ± 0.732	3.612 ± 0.837	0.039
Really eager to learn	27(52.94)	19(38.78)	0.155	3.628 ± 0.871	3.020 ± 1.031	0.002
Participation						
Actively communicate with teachers and classmates	24(47.06)	24(48.98)	0.848	3.314 ± 0.948	3.265 ± 0.884	0.793
Active group discussion	30(58.82)	28(57.14)	0.865	3.647 ± 0.934	3.510 ± 0.869	0.450
Help other students	28(54.90)	27(55.10)	0.984	3.608 ± 0.981	3.469 ± 0.960	0.478
Participate in online chat	21(41.18)	21(42.86)	0.865	3.255 ± 1.017	3.163 ± 0.965	0.645
Frequent discussions and speeches	13(25.49)	14(28.57)	0.729	2.922 ± 1.017	2.980 ± 0.854	0.758
Meet new students or learn something new about them	23(45.10)	21(42.86)	0.821	3.333 ± 1.033	3.225 ± 0.941	0.583
Manifestation						
Good performance in the quiz	30(58.82)	30(61.22)	0.806	3.549 ± 0.832	3.551 ± 0.679	0.990
High scores	19(37.25)	16(32.65)	0.630	3.225 ± 0.879	3.22 ± 0.771	0.958

(30.10±5.253;14.69±3.177) (Table 2). Further analysis revealed that in the deep learning motivation dimension, the experimental group students found exploring academic issues as engaging as reading novels and watching movies (3.294±1.006), found the content interesting enough to study diligently (3.529±1.102), and sought answers with questions in most classes (2.922±0.997). These scores were higher than those of the control group. In terms of deep learning strategies, the experimental group outperformed the control group by dedicating substantial time outside of class to researching intriguing topics discussed in class (2.961±1.019). On the shallow learning motivation dimension, students in the experimental group who exerted minimal effort to pass the course (2.373±1.095) scored significantly lower (P=0.022), as shown in Table 4. These findings suggest that the new teaching model enhances deep learning motivation.

In the TSES survey, all teachers (100%) unanimously affirmed their effectiveness of teaching in addressing students' challenging questions, managing the classroom learning atmosphere, establishing rules to ensure smooth teaching, making students abide by classroom discipline and responding to emergent problems in student learning. In addition to this, the approval rating of teachers in using formative assessment and providing an alternative explanation when students are confused was 93.33%. However, the approval rate was relatively low in the aspects of motivating students who were not interested in learning (40%), improving the comprehension of failing students (46.67%) and providing advanced challenges for students with strong abilities (40%) (Table 5). The above results show that teachers think it is easier to manage the classroom and ensure the smooth progress of teaching under the new teaching model. Furthermore, it is recommended that teachers adjust their teaching plans to accommodate both struggling students and those with strong abilities.

Discussion

In this study, the teaching model of BOPPPS combined with virtual simulation platform was implemented in preventive medicine experiments, and its effects on the performance of preventive medicine students, learning participation, learning approach and self-efficacy of teachers were good.

Enhancing students' academic performance

The experimental report results indicate that students in the experimental group achieved higher scores compared

Table 4 Results of Biggs questionnaire

Project	Score 4 and above *n* (%)			Scores		
	Experimental group	Control group	*P*-value	Experimental group	Control group	*P*-value
Deep learning motivation						
There is a deep sense of satisfaction in learning	22(43.14)	21(42.86)	0.977	3.412 ± 1.004	3.265 ± 0.930	0.451
Only diving into any problem is interesting	20(39.22)	24(48.98)	0.325	3.314 ± 1.122	3.286 ± 0.979	0.895
Exploring academic issues is as interesting as reading novels and watching movies	22(43.14)	8(16.33)	0.003	3.294 ± 1.006	2.674 ± 0.826	0.001
Studying hard because it's fun	27(52.94)	15(30.61)	0.024	3.529 ± 1.102	3.020 ± 0.854	0.011
Seek answers with questions in most classes	14(27.45)	5(10.20)	0.028	2.922 ± 0.997	2.449 ± 0.738	0.008
Deep learning strategies						
A lot of work to get answers before you are satisfied	22(43.14)	18(36.73)	0.514	3.216 ± 0.966	2.980 ± 0.989	0.230
Often take extra time to gain more knowledge	14(27.45)	13(26.53)	0.917	2.922 ± 0.997	2.898 ± 0.797	0.896
Continuous learning to understand key issues	32(62.75)	24(48.98)	0.717	3.647 ± 0.913	3.429 ± 0.957	0.246
Dedicate substantial time outside of class to researching and discussing pertinent issues	15(29.41)	6(12.24)	0.035	2.961 ± 1.019	2.531 ± 0.767	0.019
Focus on the topics taught in class	39(76.47)	30(61.22)	0.099	3.824 ± 0.953	3.571 ± 0.866	0.170
Shallow learning motivation						
Exert minimum effort to pass this course	10(19.61)	5(10.20)	0.188	2.373 ± 1.095	2.796 ± 0.676	0.022
Do as little as possible if you don't find the course interesting	5(10.20)	1(2.04)	0.102	2.373 ± 0.747	2.388 ± 0.571	0.909
Remember only the key points without trying to understand them	8(15.69)	3(6.12)	0.127	2.255 ± 1.093	2.449 ± 0.679	0.287
Just need to pass the exam without deep understanding	7(13.73)	5(10.20)	0.588	2.177 ± 1.053	2.429 ± 0.842	0.190
It is not necessary to read what is not tested	14(27.45)	9(18.37)	0.281	2.451 ± 1.189	2.592 ± 0.934	0.511
Shallow learning strategies						
Seriously study only what is required for the course syllabus	23(45.10)	10(20.41)	0.009	3.000 ± 1.281	2.735 ± 0.908	0.234
Rote memorization of points you don't understand	16(31.37)	16(32.65)	0.891	2.647 ± 1.214	2.857 ± 1.041	0.356
There is no need to do anything other than study	2(3.92)	3(6.12)	0.614	2.078 ± 0.868	2.184 ± 0.834	0.538
A teacher should not expect students to learn knowledge that will not be tested	7(13.73)	6(12.2)	0.826	2.020 ± 1.175	2.29 ± 1.02	0.230
The best way to pass an exam is to memorize the test points	13(25.49)	9(18.37)	0.390	2.490 ± 1.223	2.633 ± 0.929	0.512

to those in traditional experimental teaching within the same academic time frame. Based on the results of the correspondence analysis, educators can enhance guidance for lower-scoring experiments and students with lower scores to improve the overall quality of experimental teaching. The effectiveness of the new teaching model can be attributed to its structured learning process, which emphasizes the integration of theory and practice. The virtual simulation experiments alleviate confusion among students by offering standardized and comprehensive guidance throughout the experimental operation, creating a safe and repeatable experimental environment that facilitates deep understanding and exploration of the experimental process. Meanwhile, the BOPPPS model clarifies learning objectives and enhances student engagement and mastery by incorporating interactive feedback, which boosts motivation and initiative. It addresses the shortcomings of passive learning in virtual simulations and improves student performance. However, it places greater demands on teachers, who must adapt their teaching strategies to suit the specific learning situations of their students.

Table 5 Results of the TSES questionnaire

Project	Score 4 and above (%)	Scores
Student management		
Let the students who do not like to attend lectures as much as possible	13(86.70)	3.867 ± 0.352
Help students think critically	11(73.30)	3.733 ± 0.458
Motivate students who are not interested in learning	6(40.00)	3.333 ± 0.617
Make students believe they can do better academically	12(80.00)	4.000 ± 0.655
Cultivate students' innovation and entrepreneurship	13(86.70)	4.000 ± 0.535
Improved the understanding ability of the failing students	7(46.67)	3.600 ± 0.737
Teaching strategy implementation		
Address challenging questions from students	15(100.00)	4.333 ± 0.488
Measure students' understanding of what is being taught	13(86.70)	3.933 ± 0.458
Design good questions for students	12(80.00)	4.067 ± 0.884
Adjust course progress to each student's level	9(60.00)	3.533 ± 0.834
Use formative assessment	14(93.33)	4.267 ± 0.799
Provide an alternative explanation when the student is confused	14(93.33)	4.133 ± 0.516
Implement alternative strategies in the classroom	13(86.70)	4.000 ± 0.756
Provide advanced challenges for students with strong ability	6(40.00)	3.600 ± 0.828
Classroom management		
Manage the classroom learning atmosphere	15(100.00)	4.400 ± 0.507
Clarify the behavior expectations for students	13(86.70)	4.133 ± 0.640
Establish rules to ensure smooth teaching	15(100.00)	4.533 ± 0.516
Make students follow the rules of the project	15(100.00)	4.400 ± 0.507
Calm emotionally unstable students	11(73.33)	3.867 ± 0.640
Establish good project management links with each group of students	13(86.70)	4.000 ± 0.756
Respond to emergent problems in student learning	15(100.00)	4.267 ± 0.458

Improvements of students' autonomy and interest in learning

This study combined the two research models and found that the new model was more conducive to stimulating students' learning interest and enthusiasm and improving teaching efficiency. The SES questionnaire showed that the experimental group scored higher than the control group in terms of learning methods and learning emotions. In the learning method, the scores of pre-learning before class and keep learning of students in the experimental group were higher than those in the control group. This shows that the new teaching mode gives students a lot of autonomy in learning. Previous research has shown that effective learning methods not only improve teaching quality but also promote students' self-directed learning [18]. The enhancement of self-directed learning ability can motivate students to more effectively acquire the essential professional knowledge and skills required for preventive medicine practice. In addition, students in the experimental group were more eager to learn and more interested in the course in their learning emotions, which indicates that the BOPPPS teaching method improves the interest of students in learning. The newly teaching model prioritizes a student-centered approach with comprehensive engagement at every course stage, particularly through the use of virtual simulation. In this framework, students utilize a virtual simulation platform to conduct scenario simulations. Acting as health investigators, students are actively involved from the onset of an incident to its resolution within the virtual environment. Consequently, this model significantly enhances students' enthusiasm for experimental work compared to traditional teaching methods. These results are consistent with previous studies indicating that the utilization of virtual simulation can enhance students' sense of experience with virtual scenes and their ability to deal with emergencies [19–21]. In addition, the multi-dimensional teaching methods employed in the BOPPPS model, including pre-assessment, scene-based teaching, post-assessment, and summary sessions, enable teachers to promptly identify and address students' shortcomings. These methods not only guide students but also motivate and engage them in their learning process.

Improvements of students' deep learning motivation

Biggs questionnaire survey results show that in the preventive medicine laboratory course mixed teaching based on BOPPPS combined with the learning mode of virtual simulation platform, the score of deep learning motivation of the students in the experimental group was higher than that of the control group, indicating that the students loved learning, studied seriously and were eager to explore knowledge in the learning process. This study aligns with the findings of Berman et al. [22]. The combination mode of BOPPPS and simulation platform is connected with each other in teaching, and teachers can flexibly adjust individual links according to different teaching contents. This improves students' concentration in class. Students constantly think in the process of computer operation, which is conducive to the transformation of learning from shallow layer to deep. Moreover, this study fostered a relaxed, enjoyable, and collaborative learning environment, promoting both independent thinking and teamwork. This approach stimulated students' self-awareness and enhanced their communication and collaboration skills [23–25]. The combination of BOPPPS and virtual simulation platform enables students to participate in the whole experiment process and establish their own knowledge system. It stimulates students to think about the experiment process and experiment content and helps to improve students' innovative thinking ability and strengthen their mastery of knowledge.

The online practice model based on BOPPPS is highly recognized by teachers

Based on the findings of the TSES questionnaire employed in this research, more than 50% of educators believe that the integration of BOPPPS and the virtual simulation platform as an experimental teaching approach facilitates classroom management and the execution of instructional strategies. In addition, the new teaching model can improve "addressing challenging questions from students", "manage classroom learning atmosphere" and other aspects, all the teachers' approval rate was as high as 100%. This experimental teaching model imposes elevated demands on teachers' pedagogical proficiency. Consequently, teachers are no longer mere purveyors of knowledge, but rather assume the roles of knowledge facilitators, process supervisors, and evaluation participants. The BOPPPS teaching mode also has higher requirements for teaching quality [26]. At the same time, the results of the questionnaire showed that "motivating students who are not interested in learning" (40.0%), "improving the understanding ability of students failing" (46.67%) and "providing advanced challenges for students with strong ability" (40.0%) had low approval rates. The reason for the above may be that, on the one hand, some students only systematically follow the operation of the platform without thinking about it, and do not bring themselves into the identity of an "investigator". On the other hand, teachers did not follow up students' learning progress in time during the teaching process. It is suggested that teachers should adjust the teaching content in time according to students' virtual simulation platform results and students' feedback. More attention should be paid to students with poor academic performance so as to improve the overall experimental learning performance of students and better mobilize the enthusiasm of students. Moreover, high-achieving students should be encouraged to utilize the virtual simulation platform to conduct additional experiments beyond the classroom requirements, fostering further development of their skills.

Limitations and future directions

BOPPPS and virtual simulation platform have been paid attention to and tried in a variety of educational institutions and teaching practices, and have achieved good practice results [22, 27], but there are still some limitations and challenges. First of all, this mode requires high ability of teachers. Teachers should not only master the integration of virtual simulation platform and teaching resources, but also play a role in guiding students to think and discuss problems in offline BOPPPS classroom [6]. Secondly, the design of virtual simulation experiments remains inadequate. The feedback indicates that certain virtual simulations are overly simplistic and lack interactive elements, which diminishes students' engagement and interest in the exercises [12]. Thirdly, the quasi-experimental design of our study was unable to account for all factors, including the psychological aspects of the participants. In view of the above problems, we put forward the following prospects for the future. First of all, teachers need to adjust the teaching plan in time according to the classroom performance of students and the completion of experimental homework after class in the teaching practice, and constantly explore and summarize, to create a teaching model that is in line with themselves and students. Secondly, for the improvement of the virtual simulation platform, the development enterprises of the virtual simulation experiment platform can work together with teachers to continuously improve the application of the platform, so as to improve the learning effect and experience of students. For example, simulate more real-life scenarios, allowing students to apply their knowledge to practical problem-solving. This will enhance the realism and interest of the learning experience. Overall, although the combined use of BOPPPS with virtual simulation platforms is still in its infancy, it is foreseeable that they will receive more attention and applications in the future.

Conclusions

The purpose of this study is to compare the effects of the BOPPPS model integrated with a virtual simulation platform versus the traditional teaching model in a preventive medicine experiment. The findings suggest that the innovative teaching model significantly enhances students' experimental performance, engagement, and comprehension, while also improving their learning approaches and overall instructional efficiency in preventive medicine. Teachers believe that this new teaching model enhances classroom management and effectively stimulates student motivation. Furthermore, by utilizing the virtual simulation platform, students engaged in simulated experiments that continuously reinforced their theoretical knowledge and improved their ability to respond to public health emergencies. This approach provides valuable insights for training future professionals in public health emergency management. Future research should further explore the effects of this teaching model.

Abbreviations

BOPPPS bridge-in (B), objective (O), preassessment (P), participatory learning (P), postassessment (P) and summary (S)

BFS	Bulk food sampling
FCD	Formaldehyde content determination
OPI	Organophosphate poisoning
PPT	Power point
SES	The Students' Engagement Scale
SPI	Solanine poisoning
TSES	The Teachers' Sense of Self-efficacy

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Author contributions
C-CY contributed to the conception and design of the study and critically revised all versions of the manuscript. S-XW and MW contributed to the development of the study and analysis of the data and the writing, Y-SY, F-NY, Z-TY, Z-XN and Y-CT participated in the study conceptualization, analysed the data. All authors have read and approved the manuscript.

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Data availability
All data generated or analysed during this study are included in this manuscript.

Declarations

Ethics approval and consent to participate
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments, or comparable ethical standards. All the participants signed the informed consent, and the Binzhou Medical University Ethics Committee approved this study.

Consent for publication
All subjects have provided consent for participation and publication.

Competing interests
The authors declare no competing interests.

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