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Impacts of blended learning with BOPPPS model on Chinese medical undergraduate students: a comprehensive systematic review and meta-analysis of 44 studies

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Abstract

Background With the development of Internet information technology, especially the impact of the sudden outbreak of the novel coronavirus disease 2019 epidemic, along with the call for "classes suspended but learning continues," a large number of medical educators have learned and experienced online teaching. They have understood the shortcomings of traditional teaching methods. Not only the blended BOPPPS teaching mode combines the advantages of the BOPPPS teaching mode but also the online teaching platform breaks through the limitation of time and space. However, a general consensus on the effectiveness of the blended BOPPPS teaching strategy in China is lacking, and few studies use quantitative synthesis to evaluate the effectiveness of this teaching strategy. Hence, this study aimed to assess the overall effectiveness of online and offline blended BOPPPS teaching strategies in higher medical education in China compared with the lecture-based learning (LBL) teaching model.

Methods Studies that blended learning with the BOPPPS model in China from January 2000 to October 2023 were searched in the Chinese and English-language online databases. We analyzed the objective and subjective scores of students and performed subgroup analysis for specialties and online teaching platforms. The data were analyzed using the Stata version 14.0 software. The quality assessment was performed using the Jadad scoring scale.

Results Forty-four studies were included in this meta-analysis. Compared with the LBL mode, the blended the BOPPPS teaching mode was more effective in terms of the overall capacity [standardized mean difference (SMD) = 1.193, 95% confidence interval (CI): 0.813–1.572], mastery of medical theory knowledge (SMD = 1.090, 95% CI: 0.730–1.450), and practical skills (SMD = 1.246, 95% CI: 0.799–1.693). The analyzed questionnaire surveys indicated the positive effects of the blended BOPPPS teaching mode on classroom satisfaction, autonomous learning ability, learning interest, teamwork ability, interpersonal skills, ability to analyze and solve problems, group interaction, learning engagement, and learning strategies.

Conclusions The study underscored that the blended BOPPPS teaching mode could effectively improve the comprehensive quality of students. The subjective scores also indicated that students generally preferred this novel teaching mode.

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Keywords Blended teaching, BOPPPS, Medical education, Medical students, Meta-analysis, Teaching model, Traditional learning

Introduction

The quality of medical education is influenced by the method of education to some extent. Different educational approaches yield significant differences in teaching effectiveness. The BOPPPS teaching model originated from the Canadian teacher skill training, which was put forward by Douglas Kerrin in 1978 [1]. It is a new teaching model oriented by educational goals and centered on students, which is divided into six essential steps: bridge-in, objective, pre-assessment, participatory learning, post-assessment, and summary. In the era of rapid development of network information technology, especially influenced by the impact of the sudden outbreak of the novel coronavirus disease 2019 (COVID-19) epidemic and the imperative of the call of "classes suspended but learning continues," a large number of medical educators have learned and experienced online teaching. They have understood the disadvantages of traditional teaching methods, and promoted the development of blended teaching. Online and offline blended teaching is a learning method that relies on online high-quality resources, combines online learning with offline traditional learning, and has the advantages of the two approaches to achieve the purpose of deep learning [2].

For decades, traditional lecture-based learning (LBL) has been widely used in China [3]. In this approach, teachers deliver knowledge on the platform, and students passively receive it at their desks [4]. However, this teaching method has common shortcomings. On the one hand, this teaching method provides teacher-based indoctrination teaching, which can easily make students slack off, distracting their attention and failing to ignite their enthusiasm and initiative. On the other hand, passive listening to teachers makes students dependent and lose their ability to think independently [5]. The blended BOPPPS teaching mode not only combines the advantages of the BOPPPS teaching mode, which is, a systematic, step-by-step and actionable teaching model, but it also facilitates teachers in improving their teaching process and focuses on students' ability to participate, interact and provide feedback. According to these six steps, teachers can evaluate and modify any steps, making it extremely convenient to implement [6]. Moreover, the online teaching platform breaks through the limitations of time and space. It also effectively combines the three steps of students' pre-class preparation, in-class participation, and post-class follow-up, thereby compensating for the limitations of the traditional teaching methods. Additionally, most college students at present are born in the Internet era and hence are willing to accept the blended teaching mode [7]. Therefore, in the post-epidemic era, a hybrid approach combining the advantages of online and offline teaching is in significant demand [8].

In China, academic research in the China National Knowledge Infrastructure (CNKI) database indicates a growing focus on "blended learning" since 1997, with a significant increase in attention since 2009. By the end of 2016, the number of studies on blended learning exceeded 400 [9]. In the last 3 years, the blended teaching model has experienced a rapid expansion, driven by the impact of the COVID-19 pandemic. A large number of studies have been performed on the effectiveness of the blended BOPPPS teaching model. Most of these have pointed out that, compared with traditional lecturers, the online and offline blended BOPPPS teaching model can significantly improve teachers' instructional outcomes and students' overall capabilities [10–12]. Despite being a relatively new teaching mode, it has gained extensive adoption and has garnered valuable insights through widespread implementation in Chinese universities.

However, a comprehensive assessment of the impact of the online and offline blended BOPPPS teaching strategy in China is currently lacking. Meilan Wang. et al.'s research shows that the mixed teaching mode can effectively improve students' learning performance [13], but Li Li. et al.'s research shows that the mixed BOPPPS teaching mode has certain disadvantages. For example, it may not be effective in improving practical skills [14]. In addition, few studies use quantitative synthesis to evaluate the effectiveness of this teaching strategy. Therefore, this meta-analysis aimed to evaluate the overall effectiveness of online and offline blended BOPPPS teaching strategies in higher medical education in China compared with the LBL teaching model.

Materials and methods

Study design

This systematic review was reported following the preferred reporting items in the Cochrane Handbook for systematic reviews and meta-analysis guidelines [15]. It required no ethics approval because no human trials were performed. The main purpose of this systematic review was to assess the effectiveness of the online and offline blended BOPPPS teaching model.

Literature search

We searched PubMed, Web of Science, and Chinese online databases, such as CNKI, WanFang, VIP, and Chinese BioMedical Literature. The following keywords were used: ("BOPPPS" OR "BOPPPS mode" OR "BOPPPS teaching mode") AND ("Blended learning" OR "Blended mode teaching" OR "Blended practice teaching" OR "Blended teaching method" OR "Rain Classes" OR "Xuexi Tong" OR "Yunban Ke"). The search period was from January 2000 to October 2023.

Inclusion criteria

The studies were selected and included according to the PICOS principles in the field of evidence-based medicine. (a) Participants: Chinese medical undergraduate students. (b) Intervention: blended learning with the BOPPPS model, which incorporates online teaching, such as using "Xuexi Tong," "Yunban Ke," "Rain Classes," or other network platforms, into a BOPPPS teaching model based on our understanding of the learning characteristics of Chinese students. (c) Intervention: blended learning with the BOPPPS model, which incorporates online teaching, such as using "Xuexi Tong," "Yunban Ke," "Rain Classes," or other network platforms, into a BOPPPS teaching model based on our understanding of the learning characteristics of Chinese students. (d) Comparison: The LBL teaching method, which is a traditional teaching mode in which teachers deliver lectures and students listen to lectures. (e) Outcomes: knowledge score used to assess the students' mastery of theoretical knowledge; practical skills assessments used to evaluate students' practical problem-solving ability; total score, comprising theoretical knowledge, practical skills, and daily performance, used to estimate the overall level; and questionnaire surveys used to assess students' subjective feelings about classroom atmosphere and teaching quality. At least one of the aforementioned scores could be available. (f) Studies: randomized controlled trial.

Exclusion criteria

The exclusion criteria were as follows: (a) nonmedical undergraduate students; (b) nonrandomized controlled trials; (c) use of a teaching model other than blended learning with the BOPPPS model, such as the teaching mode of micro-class before class only and online teaching mode only; (d) control group not a pure LBL teaching model; and (e) duplicate literature.

Data extraction

Two reviewers independently completed the search and read the title, abstract, and full text of the literature to extract relevant information and data. If the search results or extracted information was inconsistent, the experts were consulted for a solution. The following information was extracted from each study: (a) author, (b) publication year, (c) sample size, (d) specialties of the students, (e) online teaching platforms, and (g) outcome measures.

Quality assessment

The revised Jadad score scale [16] (Oxford scoring system) was used to assess the quality of studies, classified as low-quality studies by score (≤ 3 points) and high-quality studies (4–7 points). The differences were resolved through discussion to reach a consensus.

Statistical analysis

The data were analyzed using the Stata version 14.0 software. The effect sizes of scores were expressed as standardized mean difference (SMD) and 95% confidence intervals (CIs). The qualitative data were expressed as odds ratios (OR) and 95% CI. The results were pooled using a fixed-effects model when heterogeneity was $\leq 50\%$ and a random-effects model when heterogeneity was $> 50\%$ [17, 18]. The sensitive analysis was used to investigate the impact of individual studies on the overall effect size. The subgroup analysis of students' specialties and online teaching platforms was conducted. The publication bias was evaluated using Egger's test [19]. P value < 0.05 indicated a statistically significant. When there is publication bias in the study, we analyze it by trim-and-fill method, and the results before and after analysis are unchanged, which means that even if there is publication bias, the final results will not be affected.

Results

Study selection

The study selection procedure is depicted in Fig. 1. We conducted an online search and found a total of 1571 articles. After removing 1193 articles unrelated to medical subjects and 210 duplicates, we were left with 168 articles. Then, we re-examined the full text of the studies for detailed evaluation. Of the remaining 46 studies, 2 had no standard deviation. Finally, the remaining 44 studies were included in our meta-analysis to analyze further the application effect of the online and offline blended BOPPPS teaching model in Chinese medical students [8, 13, 14, 20–60].

Study characteristics

The characteristics of 44 included studies published between 2017 and 2023 are listed in Table 1. In this study, the sample size was 20–518 students for the intervention group and 20–532 for the control group. The total sample size was 7004 (3487 for the experimental group and 3517

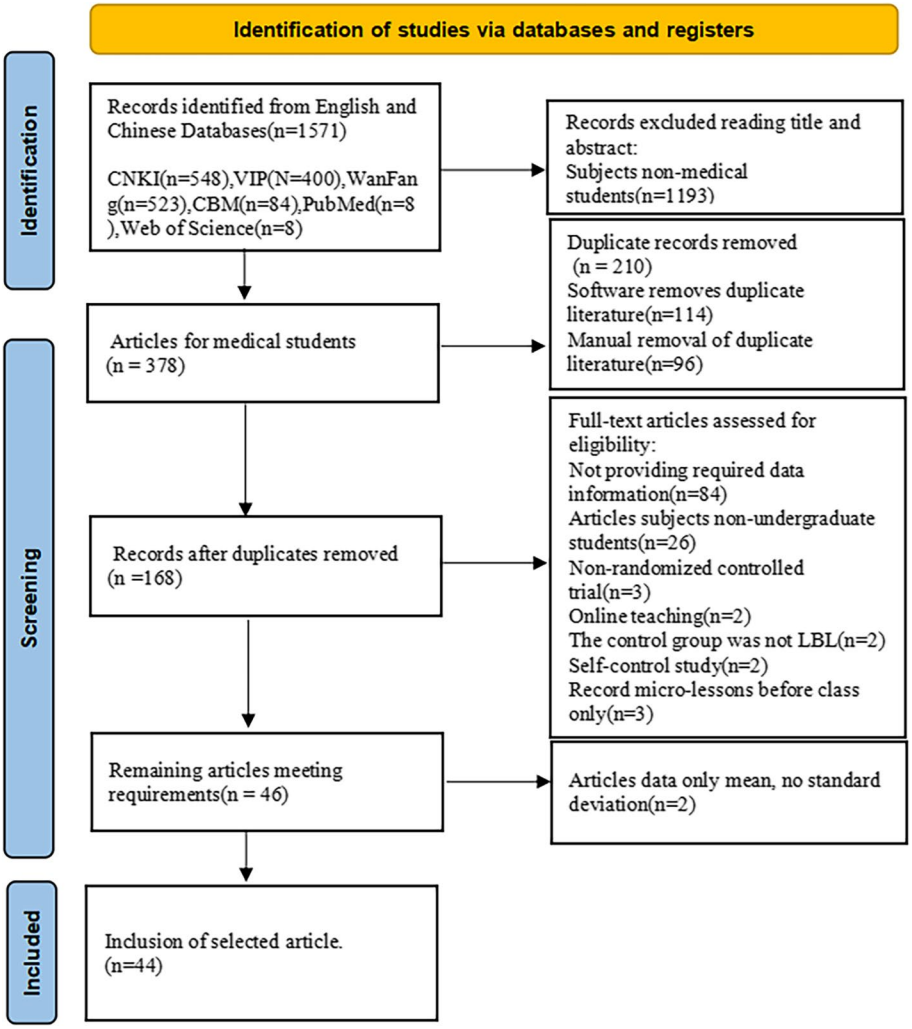

Fig. 1 Preferred reporting item for systematic reviews and meta-analysis (PRISMA) flowchart of the study retrieval and section process

for the control group). The participants included in this study were from 11 different specialties [15 nursing, 13 clinical medicine, 4 traditional Chinese medicine (TCM), 1 rehabilitation therapy technique, 1traditional Chinese pharmacology, 2 oral medicine, 1 health management, 2 pediatrics, 1 pharmaceutical engineering, 1 anesthesiology, and 3 other specialties]. The outcome measures were categorized into objective and subjective evaluations, including total score, knowledge score, practice score, satisfaction, autonomous learning ability, learning interest, teamwork ability, interpersonal skills, problem-solving ability, group interaction, learning engagement, and learning strategies.

Study quality

The Jadad scores of the 44 studies included were not high overall; 5 studies achieved scores of 4–5, which were of high quality. The remaining 39 studies were of low quality with scores of 1–3.

Influence of blended learning with the BOPPPS model on objective evaluation

A total of 13 studies with 2030 students provided total scores. Further, 39 studies with 6106 students were analyzed for knowledge scores, and 14 studies with 1565 students were used to evaluate the relationship between the new teaching model and practice scores. The hybrid BOPPPS teaching mode was related to higher total scores (SMD = 1.193; 95% CI = 0.813–1.572; $I^2 = 93.5\%$; $P < 0.001$;) knowledge scores (SMD = 1.090; 95%CI = 0.730–1.450; $I^2 = 97.5\%$; $P < 0.001$;) and practice scores (SMD = 1.246; 95% CI = 0.799–1.693; $I^2 = 94.2\%$; $P < 0.001$;) (Table 2 and Fig. 2).

A further subgroup analysis was used to stratify students by specialties and online teaching, better

Table 1 Characteristics of the included studies

	Year	Specialty	Number		Outcome measures		Online teaching platform	Jadad scale
			Experimental group	Control group	Objective evaluation	Subjective evaluation		
Xu, Y. J	2019	TCM	98	63	Total score		Xuexi Tong	2
Wang, Z. Y	2021	Nursing	106	109	Knowledge score, practice score	Autonomous learning ability, learning interest	Other	2
Wang, M. L	2021	Nursing	30	30	Knowledge score, practice score	Autonomous learning ability	Rain Classes	2
Wang, J. H	2022	TCM	60	60	Knowledge score	satisfaction	Other	2
Si, X. L	2021	Nursing	48	54	Total score, Knowledge score		Other	2
Ma, Y	2022	Pharmaceutical engineering	95	94	Total score		Xuexi Tong	2
Liu, Y	2021	Nursing	64	64	Knowledge score	problem-solving ability	MOOC	2
Li, X	2021	Clinical medicine	62	66	Total score, Knowledge score, practice score		MOOC	2
Du, X	2022	Nursing	130	127	Total score, Knowledge score	Autonomous learning ability, interpersonal skill,learning input	Xuexi Tong	2
Chen, L. L	2019	Nursing	40	40	Total score, Knowledge score	Satisfaction, Autonomous learning ability, interpersonal skill,learning strategies	Other	4
Huang, Z. J	2021	Clinical medicine	48	33	Knowledge score, practice score		Rain Classes	2
Zheng, X. D	2022	Oral medicine	64	64	Knowledge score	Autonomous learning ability, team work ability, problem-solving ability	Yunban Ke	2
Zhao, G	2019	Clinical medicine	78	78	Total score		Rain Classes	2
Zhang, Y	2022	Pediatrics	45	45	Knowledge score	satisfaction	Rain Classes	2
Shen, B. Z	2020	Clinical medicine	29	26	Knowledge score		Other	2
Liu, Y. D	2020	Clinical medicine	36	36	Knowledge score, practice score	Autonomous learning ability, learning interest, interpersonal skill,group interaction	Other	4
Liu, X. X	2020	Nursing	111	110	Knowledge score	Autonomous learning ability, team work ability	Rain Classes	4
Li, J	2021	Clinical medicine	20	20	Knowledge score	Autonomous learning ability,interpersonal skill,group interaction	Rain Classes	2
Jia, J	2022	Clinical medicine	34	34	Knowledge score		Other	2
Gao, P. C	2021	Rehabilitation therapy technique	62	61	Total score, Knowledge score, practice score	Autonomous learning ability,learning interest, interpersonal skill	Xuexi Tong	2
Liu, X. Y	2022	Clinical medicine	518	532	Knowledge score		Xuexi Tong	2
Liu, D	2020	other	236	241	Knowledge score		Yunban Ke	2
Ma, X	2021	Health Management	55	54	Total score, Knowledge score	Autonomous learning ability, interpersonal skill,interpersonal skill, problem-solving ability,group interaction	Rain Classes	4
Zhang, C. L	2020	other	130	160	Knowledge score		SPOC	2
Zhang, Y. J	2017	Pediatrics	72	70	Knowledge score		Other	2
Yang, X. H	2019	Clinical medicine	60	60	Knowledge score, practice score		Other	2
Xue, J. L	2018	Nursing	66	64	Knowledge score	Learning input,learning strategies	Other	2

Table 1 (continued)

	Year	Specialty	Number		Outcome measures		Online teaching platform	Jadad scale
			Experimental group	Control group	Objective evaluation	Subjective evaluation		
Li, L	2021	Clinical medicine	81	74	Knowledge score, practice score		Other	2
Chen, P. P	2022	Nursing	45	45	Knowledge score, practice score	Interpersonal skill	Other	2
Zhang, P	2021	Nursing	39	40	Knowledge score	Autonomous learning ability,team work ability	Xuexi Tong	2
Zhang, L	2023	Clinical medicine	60	60	Knowledge score		Xuexi Tong	2
Zhang, L. J	2019	Nursing	114	112	Knowledge score	Autonomous learning ability,Interpersonal skill	Rain Classes	2
Xu, Y. Z	2022	Nursing	143	187	Total score	Autonomous learning ability,learning strategies,team work ability,Interpersonal skill	Rain Classes	2
Cui, J. Z	2022	TCM	36	36	Knowledge score	Satisfaction,Autonomous learning ability,learning interest,problem-solving ability	Rain Classes	2
Liu, Y	2022	Oral medicine	26	26	Total score, Knowledge score, practice score	Autonomous learning ability,team work ability,problem-solving ability	Other	2
Chu, F. F	2022	Clinical medicine	54	54	Total score, Knowledge score, practice score	Satisfaction	Xuexi Tong	2
Hao, S. J	2023	Nursing	50	55	Knowledge score	Autonomous learning ability,team work ability	Xuexi Tong	2
Cheng, C	2022	Clinical medicine	30	32		Satisfaction	Rain Classes	2
Cai, Z. H	2022	Anesthesiology	26	25	Knowledge score		Rain Classes	4
Peng, S. N	2023	TCM	97	96	Knowledge score		Xuexi Tong	2
Zhou, Q	2023	Nursing	57	60	Knowledge score		Xuexi Tong	2
Yu, L. R	2023	Traditional Chinese pharmacology	50	48	Knowledge score, practice score	problem-solving ability	MOOC	2
Xu, Z. F	2023	other	121	114	Total score, Knowledge score, practice score		Other	2
Zhao, B. W	2023	Nursing	61	58	Knowledge score, practice score	team work ability	Rain Classes	2

Table 2 The influence of blended learning with BOPPPS model on objective evaluation

Objective evaluation	SMD	CI	N	I^2	*P*
Total scores	1.193	0.813–1.572	13	93.5%	$P<0.001$
Knowledge scores	1.090	0.730–1.450	39	97.5%	$P<0.001$
Practice scores	1.246	0.799–1.693	14	94.2%	$P<0.001$

assessing the association between the new teaching model and high scores. High scores were correlated with the new teaching model across all specialties in terms of the total score assessment, knowledge score assessment, and practical score assessment. The application of different online teaching platforms could basically improve students' total scores, knowledge scores, and practical scores. However, no significant difference was observed in the knowledge scores of students majoring in TCM. The use of Rain Classes teaching did not improve students' total scores, and the use of Xuexi Tong was not significant in the evaluation of students' practice scores (Table 3).

The sensitivity analysis of results with high heterogeneity showed that the deletion of any one study had no significant effect on overall effect size (Fig. 3).

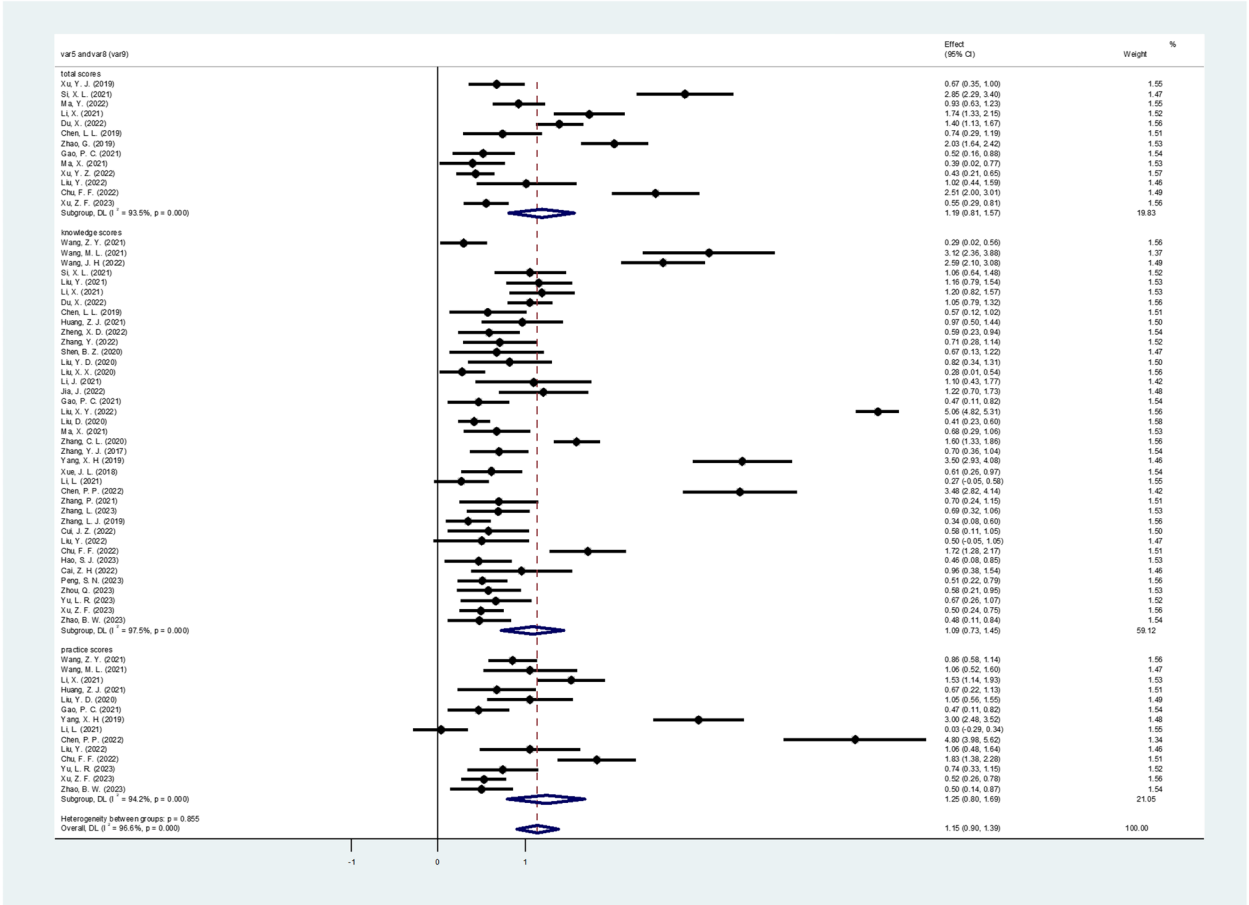

Fig. 2 Forest plot on objective evaluation score

Influence of blended learning with the BOPPPS model on subjective evaluation

A total of 6 studies with 532 students provided satisfaction, 16 studies with 2169 students were analyzed for autonomous learning ability, 4 studies with 482 students were analyzed for learning interest, 7 studies with 1034 students were analyzed for teamwork ability, 9 studies with 1327 students were analyzed for interpersonal skill, 6 studies with 587 students were analyzed for problem-solving ability, 3 studies with 221 students were analyzed for group interaction ability, 2 studies with 387 students were analyzed for learning engagement, and 3 studies with 540 students were used to evaluate the relationship between the new teaching model and learning strategies. The mixed BOPPPS teaching mode was related to high satisfaction (OR = 1.381; 95% CI = 1.261–1.512; $I^2 = 68.5\%$; $P = 0.007$), autonomous learning ability (SMD = 0.825; 95% CI = 0.610–1.041; $I^2 = 81.9\%$; $P < 0.001$), learning interest (SMD = 0.735; 95% CI = 0.350–1.119; $I^2 = 74.1\%$; $P = 0.009$), team work ability SMD = 0.846; 95% CI = 0.504–1.188; $I^2 = 84.5\%$; $P < 0.001$;), interpersonal skills (SMD = 0.851; 95% CI = 0.378–1.324; $I^2 = 93.7\%$; $P < 0.001$), problem-solving ability (SMD = 0.786.; 95% CI = 0.353–1.220; $I^2 = 84.2\%$; $P < 0.001$;), group interaction (SMD = 0.804; 95% CI = 0.530–1.079; $I^2 = 0.0\%$; $P = 0.590$), learning engagement (SMD = 0.747; 95% CI = 0.494–1.000; $I^2 = 25.1\%$; $P = 0.248$), and learning strategies (SMD = 0.524; 95% CI = 0.375–0.674; $I^2 = 0.0\%$; $P = 0.972$) (Table 4).

A further subgroup analysis was used to stratify students by specialties and online teaching platform in projects where the number of studies included was five or more to assess better the association between the new teaching model and high scores. The results indicated that the new teaching model was related to high scores across all specialties in evaluating satisfaction, autonomous learning ability, and teamwork ability. Furthermore, the use of various network teaching platforms enhanced the effectiveness of the blended BOPPPS teaching approach, which also correlated with high scores. However, no significant difference was found in interpersonal skills assessment of students majoring in

Table 3 Subgroup analysis was used to stratify students by specialties and online teaching platforms

Objective evaluation	Concomitant variable		N	SMD	CI	I^2	P
Total scores	Specialties	Nursing	4	1.329	0.473–2.184	96.1%	$P<0.001$
		Clinical medicine	3	2.068	1.661–2.475	62.6%	$P=0.069$
		other specialties	6	0.657	0.483–0.832	34.7%	$P=0.176$
	Online teaching platforms	Xuexi Tong	5	1.184	0.639–1.728	92.3%	$P<0.001$
		Rain Classes	3	0.944	-0.025–1.913	96.3%	$P<0.001$
		other	5	1.365	0.589–2.141	94.0%	$P<0.001$
Knowledge scores	Specialties	Nursing	14	0.944	0.614–1.274	91.5%	$P<0.001$
		TCM	3	1.216	-0.026–2.457	96.4%	$P<0.001$
		Oral medicine	2	0.561	0.263–0.859	0%	$P=0.788$
		Pediatrics	2	0.704	0.439–0.970	0%	$P=0.967$
		Clinical medicine	11	1.568	0.400–2.736	98.9%	$P<0.001$
		other specialties	7	0.749	0.384–1.113	89.7%	$P<0.001$
	Online teaching platforms	Xuexi Tong	9	1.252	0.027–2.476	99.2%	$P<0.001$
		Rain Classes	10	0.839	0.505–1.174	84.6%	$P<0.001$
		MOOC	3	1.018	0.692–1.344	53.3%	$P=0.118$
		Yunban Ke	2	0.450	0.289–0.612	0%	$P=0.393$
		other	15	1.201	0.765–1.636	94.7%	$P<0.001$
Practice scores	Specialties	Nursing	4	1.742	0.538–2.945	96.7%	$P<0.001$
		Clinical medicine	6	1.343	0.515–2.172	95.6%	$P<0.001$
		Other specialties	4	0.615	0.410–0.820	18.8%	$P=0.296$
	Online teaching platforms	Rain Classes	3	0.695	0.390–1.000	29.1%	$P=0.244$
		MOOC	2	1.138	0.364–1.911	86.5%	$P=0.007$
		Xuexi Tong	2	1.140	-0.195–2.475	95.4%	$P<0.001$
		other	7	1.565	0.733–2.397	96.8%	$P<0.001$

other specialties. The use of Xuexi Tong did not improve students' interpersonal skills, and the use of Rain Classes teaching was not significant in evaluating students' problem-solving ability (Table 5).

The sensitivity analysis of results with high heterogeneity showed that the deletion of any one study had no significant effect on the overall effect size (Fig. 4).

Publication bias

We assessed the publication bias of the research on the online and offline hybrid BOPPPS teaching model in Chinese medical undergraduate teaching. The result showed no significant publication bias except in assessing total scores, practice scores, satisfaction, teamwork ability, and interpersonal skills. All combined SMD/OR values remained significant even after applying the trim-and-fill method when assessing total scores, practice scores, satisfaction, teamwork ability, and interpersonal skills (Tables 6 and 7).

Discussion

This meta-analysis was novel in comprehensively examining the effectiveness of blended BOPPPS teaching strategies in medical education in China. It analyzed 44 studies on the teaching effect of the online and offline blended BOPPPS teaching model for medical undergraduates in our country. We found that the blended BOPPPS teaching model was a novel and effective teaching model that improved students' overall quality of education. The subjective scores also showed that students generally preferred this new teaching mode.

BOPPPS is one of the most popular teaching models in universities in North America. It is a systematic teaching model that follows step-by-step teaching and emphasizes the participation and feedback of students. This model has been recommended for use in more than 33 countries and promoted by more than 100 universities and training institutions globally [61]. In China, the hybrid BOPPPS teaching mode combines traditional teaching and online teaching organically, learning from each other's strengths, aiming at effectively expanding teaching time and space and improving teaching quality [62]. It is conducive to teaching students according to their aptitude, identifying disparities in students' learning, and offering personalized and targeted suggestions to engage students, promote learning, and address the challenges they encounter in their educational journey [63]. The six components of the online and offline blended BOPPPS

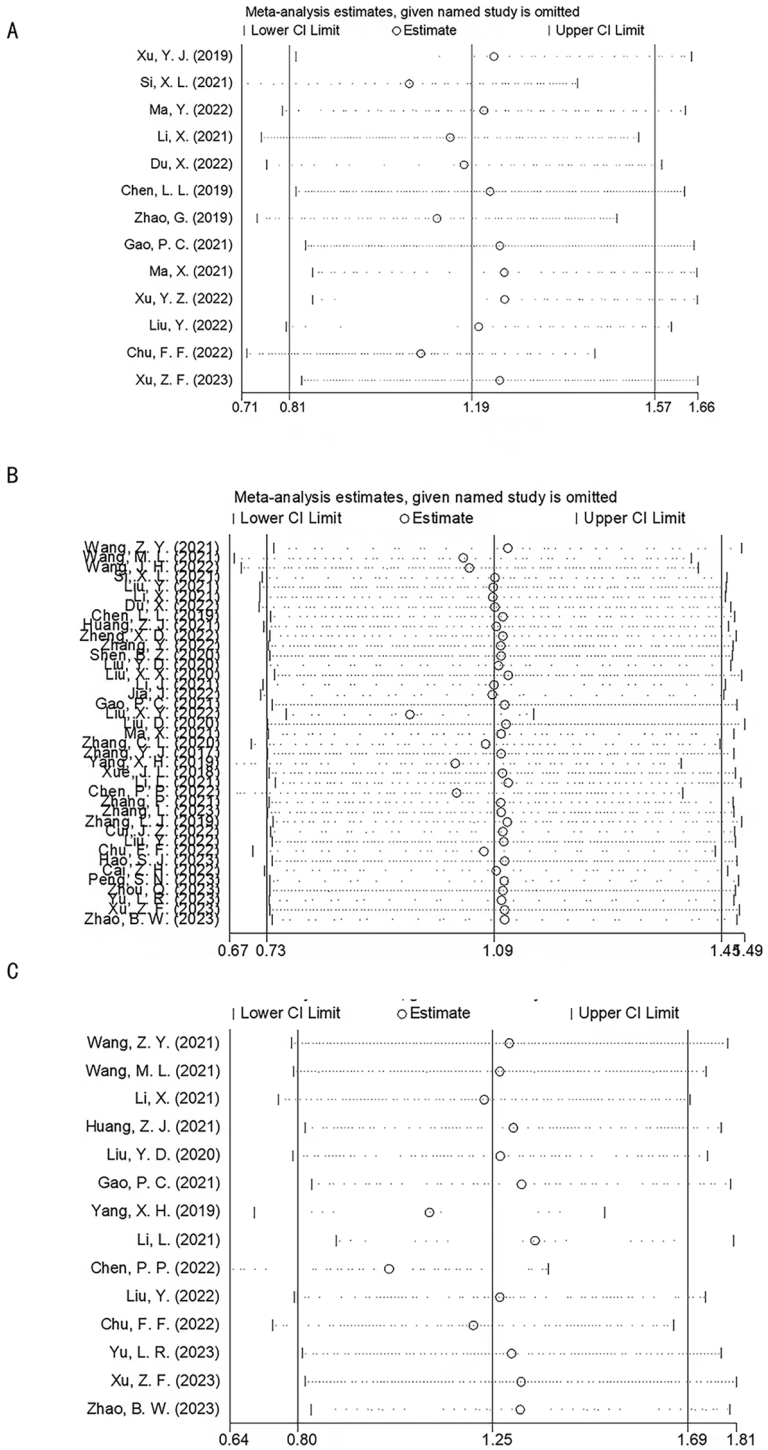

Fig. 3 The sensitivity analysis of blended BOPPPS teaching model and objective evaluation score. **A** total scores. **B** knowledge scores. **C** practice scores

teaching mode are closely interconnected, underscoring the significance of students' principal position in the teaching process and effectively enhancing students' participation in classroom teaching. Bridge-in constitutes the first step in the complete teaching cycle. Teachers carefully design questions and select classic cases, hot

Table 4 The influence of blended learning with BOPPPS model on subjective evaluation

Subjective evaluation	SMD/OR	N	CI	I^2	P
Satisfaction	1.381	6	1.261–1.512	68.5%	$P=0.007$
Autonomous learning ability	0.825	16	0.610–1.041	81.9%	$P<0.001$
Learning interest	0.735	4	0.350–1.119	74.1%	$P=0.009$
Team work ability	0.846	7	0.504–1.188	84.5%	$P<0.001$
Interpersonal skill	0.851	9	0.378–1.324	93.7%	$P<0.001$
Problem-solving ability	0.786	6	0.353–1.220	84.2%	$P<0.001$
Group interaction	0.804	3	0.530–1.079	0.0%	$P=0.590$
Learning engagement	0.747	2	0.494–1.000	25.1%	$P=0.248$
Learning strategies	0.524	3	0.375–0.674	0.0%	$P=0.972$

topics, and social phenomena related to the curriculum as pre-class introduction resources through the online teaching platform [64]. In the pre-test phase, teachers can generate 10–20 exercises aligned with teaching objectives online for small tests, provide timely feedback on learning results, and assess each student's grasp of key concepts, with timely adjustments to improve the efficiency and quality of teaching [65]. The next step, participatory learning, represents the pivotal component of the BOPPPS teaching model. This phase focuses on unleashing students' subjective initiative, placing students at the core, and emphasizing their active involvement. Teachers can stimulate students' enthusiasm and interest in learning by organizing in-class discussions or online discussions by posting comments on an online platform to engage in discussions and receive online responses. Teachers can also pinpoint key points and challenging areas from the curriculum and carry out targeted teaching practices. For key knowledge, the approach of group reporting, explanations, and questions is used, while applied knowledge is taught through role-playing, involving both students and teachers. In combination with the presentation of the results of each group, the teacher affirms the innovations presented by each group,

Table 5 Subgroup analysis was used to stratify students by specialties and online teaching platforms

Subjective evaluation	Concomitant variable		N	SMD/OR	CI	I^2	P
Satisfaction	Specialties	TCM	2	1.706	1.402–2.076	3.2%	$P=0.309$
		Clinical medicine	2	1.235	1.097–1.390	58.5%	$P=0.120$
		other specialties	2	1.267	1.084–1.480	0%	$P=0.365$
	Online teaching platforms	Rain Classes	3	1.521	1.293–1.790	35.1%	$P=0.214$
		other	3	1.297	1.166–1.443	75%	$P=0.018$
Autonomous learning ability	Specialties	Nursing	9	0.791	0.508–1.073	85.6%	$P<0.001$
		Clinical medicine	2	1.246	0.839–1.652	0%	$P=0.511$
		Oral medicine	2	1.296	0.974–1.618	0%	$P=0.957$
		other specialties	3	0.433	0.204–0.662	0.8%	$P=0.365$
	Online teaching platforms	Rain Classes	7	0.558	0.368–0.748	50.4%	$P=0.06$
		Xuexi Tong	4	0.989	0.432–1.546	89.0%	$P<0.001$
		other	5	1.015	0.617–1.413	77.5%	$P=0.001$
team work ability	Specialties	Nursing	5	0.664	0.344–0.985	77.8%	$P=0.004$
		Oral medicine	2	1.400	0.301–2.500	88%	$P=0.004$
	Online teaching platforms	Rain Classes	3	0.499	0.136–0.861	80%	$P=0.007$
		Xuexi Tong	2	0.953	0.647–1.258	0%	$P=0.671$
		other	2	1.400	0.301–2.500	88%	$P=0.004$
interpersonal skill	Specialties	Nursing	5	1.098	0.374–1.822	96.3%	$P<0.001$
		Clinical medicine	2	1.069	0.181–1.956	76.9%	$P=0.037$
		other specialties	2	0.107	-0.412–0.625	75.1%	$P=0.045$
	Online teaching platforms	Xuexi Tong	2	0.199	-0.063–0.460	35.3%	$P=0.214$
		Rain Classes	4	0.464	0.043–0.886	84%	$P<0.001$
		other	3	1.868	0.085–3.651	96.9%	$P<0.001$
problem-solving ability	Specialties	Oral medicine	2	1.384	0.273–2.496	88.3%	$P=0.003$
		Other specialties	4	0.528	0.106–0.950	77.3%	$P=0.004$
	Online teaching platforms	Rain Classes	2	0.319	-0.489–1.127	85.9%	$P=0.008$
		MOOC	2	0.739	0.470–1.009	0%	$P=0.835$
		other	2	1.384	0.273–2.496	88.3%	$P=0.003$

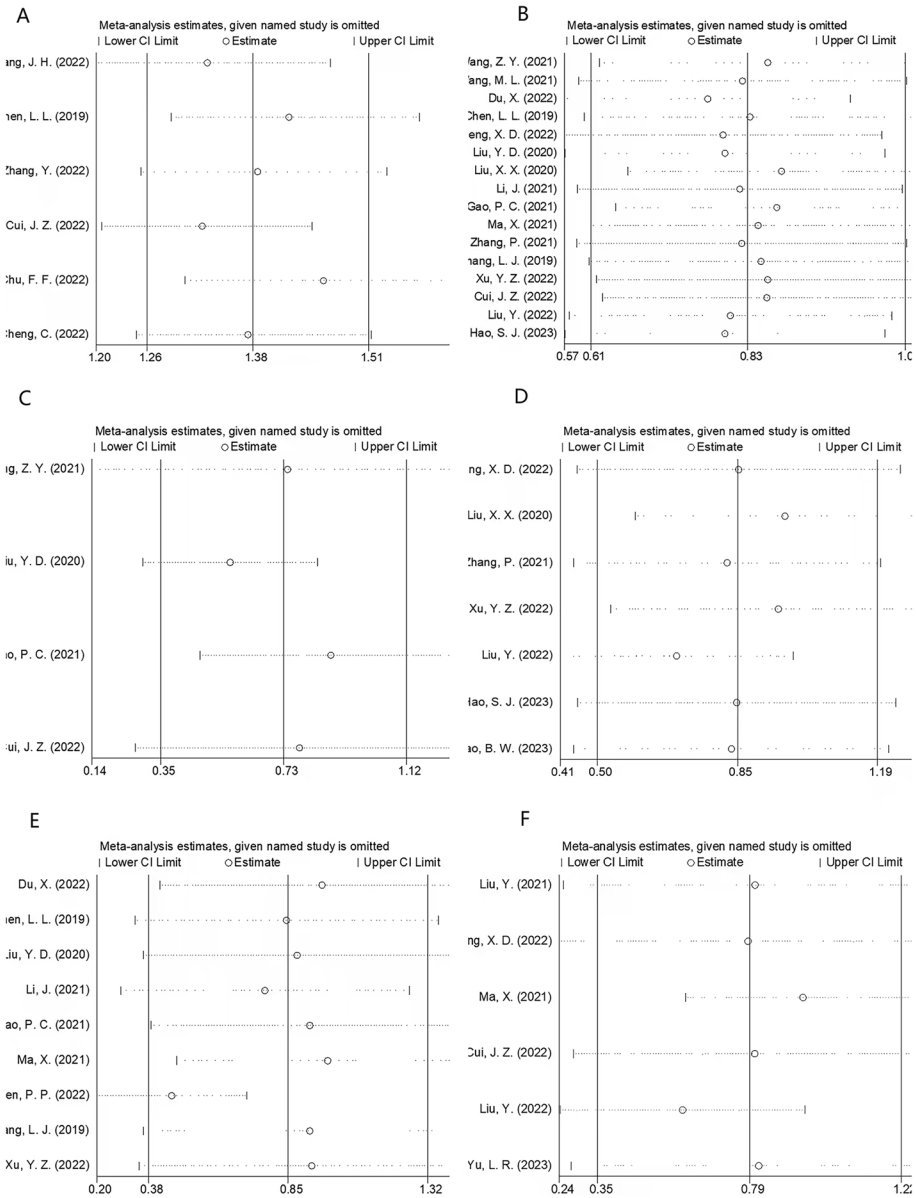

Fig. 4 The sensitivity analysis of blended BOPPPS teaching model and subjective evaluation score. **A** satisfaction. **B** autonomous learning ability. **C** learning interest. **D** team work ability. **E** interpersonal skill. **F** problem-solving ability

addresses the objections of other students, highlights the merits of the supplement, and identifies the shortcomings of each group [66]. Relevant research shows that pictures and texts enhance students' enthusiasm for participatory and interactive learning and facilitate backup and storage through video-sharing learning or interactive exchange [67]. The post-test link is designed to assess students' learning achievements; this involves self-testing through textbook exercises and platform supplementary contact to test their grasp of the teaching content in the unit. Students complete the assigned tasks and realize knowledge transfer [68]. In summary, the final component of the teaching cycle is the feedback and sublimation of the entire teaching process. The summarization of the content learned spans both in-class and post-class phases. In-class summarization involves organizing and consolidating the knowledge acquired, whereas post-class summarization occurs when students finish their homework or practice and they engage in deep reflection on the knowledge, representing an additional layer of summarization [69]. These six stages collectively form a coherent, systematic, and actionable teaching design

Table 6 Egger test of objective evaluation and subjective evaluation score

Publication bias	Egger	
	t	*P*
Total scores	2.49	0.030
Knowledge scores	0.57	0.569
Practice scores	3.44	0.005
Satisfaction	2.80	0.049
Autonomous learning ability	1.72	0.107
Learning interest	0.57	0.627
Team work ability	6.20	0.002
Interpersonal skill	2.56	0.037
Problem-solving ability	1.71	0.162
Group interaction	2.10	0.283
Learning engagement	\	\
Learning strategies	-0.17	0.895

Table 7 T&F(Fill) method analysis

Publication bias	T&F(Fill) method analysis		Model
	Before	After	
Total scores	1.193(0.813,1.572)	3.296(2.256,4.815)	random
		2.650(2.411,2.913)	fixed
Practice score	1.246(0.799,1.693)	3.477(2.224,5.434)	random
		2.472(2.226,2.746)	fixed
Satisfaction	1.381(1.261,1.512)	1.203(1.034,1.400)	random
		1.193(1.111,1.281)	fixed
Team work ability	0.846(0.504,1.188)	2.035(1.419–2.918)	random
		1.797(1.587–2.035)	fixed
Interpersonal skill	0.851(0.378,1.324)	1.346(0.783,2.314)	random
		1.343(1.208,1.494)	fixed

model, providing a robust framework for achieving effective teaching outcomes.

Our results revealed that the objective and subjective assessment scores of the mixed BOPPPS teaching group were higher than those of the traditional teaching group. Everal factors accounted for these results. First, compared with the traditional learning mode, the blended BOPPPS teaching mode allowed students to engage in pre-class preparation and post-class review, thus improving their academic performance. Second, this teaching mode was relatively novel, which could significantly improve students' interest and initiative in subject-based learning. Third, the teaching model provided students with a clear learning goal, which might make students study more purposefully and thus get higher grades. We found that applying the mixed BOPPPS teaching mode improved students' practical ability, which was in line with the student-centered teaching concept of the BOPPPS teaching mode. Through participative learning, students had more practical opportunities and improved practical skills. At the same time, the questionnaire scores also showed that the teaching model was widely welcomed by students, with good feedback regarding both classroom satisfaction and other subjective evaluations such as autonomous learning ability. This also reflected that the blended teaching mode had a significant advantage in creating a good classroom atmosphere and improved teaching quality. Although various methods were used to maintain interactivity in learning during online courses, some students still provided feedback that the classroom interaction was poor [70]. Our study showed that using the online and offline hybrid BOPPPS teaching model contributed to the interaction between students and students, and between students and teachers. For this distinction, we believed that the mixed teaching mode had the dual advantages of both online and offline teaching and effectively made up for the lack of interaction in online teaching. However, in objective evaluation, no significant difference was found in the knowledge scores of students majoring in TCM. We suspect that this was because fewer TCM articles were included, as the original articles all showed that students in the BOPPPS group scored higher and the results were significant. The use of Rain Classes teaching did not improve students' total scores, and the use of Xuexi Tong was not significant in evaluating students' practice scores. We believe that the results could be changed if more articles could be included, as the original shows significant differences. In subjective evaluation, no significant difference was observed in interpersonal skills assessment of students majoring in other specialties. This may be due to the fact that we incorporate oral communication skills into interpersonal skills, which may not be the same. The use of Xuexi Tong did not improve students' interpersonal skills, and the use of Rain Classes teaching was not significant in evaluating students' problem-solving ability. This may be due to the small number of literature and the difference between the two teaching platforms. To sum up, these results might be explained by many factors. First, the results might not be significant due to the small number of studies included in some aspects of the analysis. Second, the heterogeneity of the literature might also contribute to the variation in results. Thirdly, some of the indicators included may not be equivalent. Finally, differences in learning platform might play a role. The Rain Classes was jointly developed by the online school and the online education office of Tsinghua University, allowing teachers to deliver MOOC videos, quizzes, and other materials through online platforms for students to access before class. Teachers and students can also

interact with each other on the network platform. Rain Classes scientifically covers every teaching phase before, during, and after class, enhancing the clarity of teaching and learning. Xuexi Tong serves as the integrated terminal for products offered by a company Superstar, providing access to various educational resources, curriculum materials, social tools, and public communities. Compared with Xuexi Tong, Rain Classes main focuses on supporting the flipped classroom approach, various resources such as novels that are not available. These two educational platforms are constantly growing in response to the continuous development of network information technology in China. Also, the outbreak of COVID-19 has accelerated the adoption and use of online education platforms, significantly enhancing their implementation in colleges and universities. In summary, these two different software may bring different outcomes in teaching effectiveness. Although we believe that different teaching platforms produce different teaching effects, in this paper, only a few articles were included due to our multilevel subgroup analysis. Therefore, we suspect that the lack of significant results is largely due to the low number of articles included.

However, some obvious heterogeneity was detected among the majority of studies. Several possible sources of high heterogeneity in some results were as follows. First, the teaching quality provided by the teachers was a crucial factor in cultivating students. Teachers from different schools and regions may have different levels of teaching expertise, leading to substantial differences in teaching effectiveness. Although all of the studies included in this study were mostly conducted in higher medical schools or their affiliated hospitals, only a small number of studies discussed of the teacher's teaching proficiency. In addition, the teachers' understanding of the blended BOPPPS model and teaching practice was different. Although teachers were familiar with blended learning with the BOPPPS teaching mode and made extensive attempts, only a small number of teachers received systematic teaching training. Second, the students' desires to learn and abilities were different. Some students attempting to get a scholarship might have a strong learning aspiration and ability. Therefore, we believed that students' learning ability was also a source of heterogeneity.

However, our study had several unavoidable limitations. Besides the heterogeneity discussed earlier, the results of the quality evaluation of included studies were also one of the limitations of this meta-analysis. The reason for the low literature score was that the Jadad scores were suitable for clinical randomized clinical trials and teaching trials. The blind methods could not be designed, and hence the study scores were generally lower. The small sample size of some studies might have led to inaccurate results, which was another limitation of this study. Moreover, because of the characteristics of the teaching process, most of the studies included might be randomized at the time of grouping; however, students knew their grouping as the teaching progressed, leading to information bias. Finally, many students will encounter difficulties in adapting to new learning methods, which may affect the final results [56].

Conclusions

This meta-analysis demonstrated that the blended online and offline BOPPPS teaching model was more effective than LBL in improving students' medical theory knowledge and practical operational skills in mainland China. The questionnaire surveys revealed the positive impacts of the blended teaching model on classroom satisfaction, autonomous learning ability, learning interest, teamwork skills, interpersonal abilities, problem-solving ability, group interaction, learning engagement, and learning strategies. The results of this study fully reflect the advantages of the hybrid BOPPPS teaching compared with the traditional teaching. This allows us to understand that the online and offline blended BOPPPS teaching model is really effective, it can stimulate students' potential, improve students' performance and is worth popularizing in medical colleges and universities.

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Authors' contributions
XinChen designed the study, obtained funding and oversaw the project. Xiaofeng Li, Li Ma, Qiujuan Li, Xiance Sun and Xin Chen collected the data. Shuze Li and Wei Wei analyzed data and wrote the manuscript. All authors reviewed the manuscript.

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Availability of data and materials
The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable (This manuscript is a meta-analysis, and does not report on or involve the use of any animal or human data or tissue.)

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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