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RESEARCH

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Which novel teaching strategy is most recommended in medical education? A systematic review and network meta-analysis

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Abstract

Aim There is no conclusive evidence which one is the optimal methodology for enhancing the quality and efficacy of learning for medical students. Therefore, this systematic review and network meta-analysis aims to evaluate and prioritize various teaching strategies in medical education, including simulation-based learning (SBL), flipped classrooms (FC), problem-based learning (PBL), team-based learning (TBL), case-based learning (CBL), and bridge-in, objective, pre-assessment, participatory learning, post-assessment, and summary (BOPPPS).

Methods We conducted a comprehensive systematic search of PubMed, Embase, Web of Science, the Cochrane Library, and some key medical education journals up to November 31, 2023. The following keywords were searched in MeSH: ("medical students") AND ("problem-based learning" OR "problem solving") AND ("Randomized Controlled Trials as Topic"). Two authors independently carried out data extraction and quality assessment from the final selection of records following a full-text assessment based on strict eligibility criteria. Pairwise and network meta-analyses were then applied to calculate pooled standardized mean differences (SMDs) and 95% confidence intervals (95%CIs) using a random-effects model. Statistical analysis was performed by R software (4.3.1) and Stata 14 software.

Results A total of 80 randomized controlled trials with 6,180 students were included in the study. Compared to LBL, CBL (SMD = 1.19; 95% CI 0.49–1.90; $p < 0.05$; SUCRA = 89.4%), PBL (SMD = 3.37; 95% CI 1.23–5.51; $p < 0.05$; SUCRA = 93.3%), and SBL (SMD = 2.64; 95% CI 1.28–4.00; $p < 0.05$; SUCRA = 96.2%) were identified as the most effective methods in enhancing theoretical test scores, experimental or practical test scores, and students' satisfaction scores, respectively. Furthermore, subgroup analysis indicated that CBL (SUCRA = 97.7%) and PBL (SUCRA = 60.3%) were the most effective method for enhancing learning effectiveness within clinical curricula.

Conclusions Among the six novel teaching strategies evaluated, CBL and PBL are more effective in enhancing the quality and efficacy of learning for medical students; SBL was determined to offer a superior learning experience throughout the educational process. However, this analysis revealed only minor differences among those novel teaching strategies.

Keywords Network Meta-Analysis, Systematic Reviews, Medical Education, Medical Students, Teaching, Learning

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Introduction

Medical education, recognized as one of the most stressful fields of education, presents inherent challenges due to its rigorous academic requirements and professional standards [1]. Medical students often encounter substantial physical and mental stress, attribute to the extensive curriculum, sleep disturbances, complex subject matter, and abstract terminology [1–4]. In context of medical education, the teaching strategies employed within the classrooms play a major role in improving the academic performance and clinical skills [5]. Nevertheless, the conventional lecture-based learning (LBL) method, which has historically dominated educational environments, may fall short in equipping students for the multifaceted challenges of medical practice [5, 6]. Therefore, efforts are warranted to ameliorate current educational landscape and modes in medicine to ensure high quality of learning for students and align with the evolving healthcare industry [7, 8].

In recent years, numerous novel teaching strategies have been proposed and widely used in medical education. In modern educational settings, case-based learning (CBL), problem-based learning (PBL), and team-based learning (TBL) are prominent and widely adopted approaches [9]. These three strategies are more oriented towards practical problems or clinical cases. Through team discussions and collaboration, students integrate knowledge to enhance their abilities to analyze and solve problems [10]. The bridge-in, objective, preassessment, participatory learning, post-assessment, and summary (BOPPPS) strategy, proposed by Douglas Kerrin in 1978, has made great accomplishments in medical disciplines education [11]. This strategy is organized into six steps, allowing educators to engage students by crafting captivating scenarios. Teachers can encourage students to discuss clinical cases, identify and solve problems, and ultimately summarize their findings to develop a comprehensive knowledge framework [12]. Additionally, with the rapid development of computer technology and mobile internet, flipped classroom (FC) and simulation-based learning (SBL) have been broadly applied in virtual education [13, 14]. Educational internet and activity-based learning enlarge the level of knowledge and ability of the students through quick and cost-effective access to information and scientific resources [15]. For a comprehensive evaluation of these instructional strategies, refer to supplemental appendix 1. Prior pairwise meta-analyses have demonstrated the considerable efficacy of these innovative strategies in improving students' academic performance, subjective enthusiasm, and overall competencies [16–19]. Furthermore, these novel teaching strategies underscore the student-centered teaching concept and promote students' communication skills and collaborative assistance [20, 21]. In this process, students can share their learning experience, which facilitates the enhancement of their academic performance and clinical practice ability.

However, controversy regarding the most effective method for enhancing learning quality remains, as many novel teaching strategies have yet to be directly compared in previous studies. Besides, conflicting findings from different meta-analyses may hinder the widespread adoption of these novel teaching strategies in both classroom and clinical settings [22–25]. Although it is recommended to carefully evaluate the specific context when implementing novel teaching strategies [26], there is a lack of research to substantiate this viewpoint. These issues contribute to uncertainty in decision-making among administrators and educators. From the perspective of evidence-based medicine, systematic reviews and network meta-analyses (NMA) are regarded as the most contemporary and highest level of evidence [27], and could be adopted in the field of medical education, especially in scenarios where direct comparative studies of innovative teaching strategies are scarce. The present NMA aims to synthesize, assess, and rank the existing evidence on six commonly used methods for improving learning outcomes among medical students.

Methods

This systematic review and NMA was carried out following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) extension statement [28], which aimed to compare the effectiveness of six single teaching strategies in improving the learning of medical students through the analyses of three specific indices [29, 30]. This review was exempt from the need for ethical approval since the data were obtained from published studies, and detailed participant information was not disclosed to the public. The protocol has been registered (registration number: CRD42023456050) in the international prospective register of systematic reviews (PROSPERO) and subsequently published in BMJ Open [31]. Any changes to the original protocol are presented in the supplemental appendix 2.

Search strategy and selection criteria

Two authors (SLZ and DMZ) performed a comprehensive literature review utilizing both database and manual search strategies. A systematic search was conducted across multiple electronic databases, including PubMed, Embase, Web of Science, and the Cochrane Library, covering the period from the inception of each database—1997 for PubMed and Embase, 1988 for Web of Science, and 1993 for the Cochrane Library—up to November 30, 2023. The reproducible search strategies were performed based on the population, intervention, comparison, and outcome (PICO) principle, as elaborated in the supplementary appendix 3. Furthermore, relevant randomized controlled trials (RCTs) were identified through manual searches from the reference lists of pertinent meta-analyses and leading medical education journals.

ENDNOTE 20 literature management software (Clarivate, Philadelphia, PA, USA) was utilized to independently screen all retrieved studies by two authors (HG and SLZ) based on predefined inclusion and exclusion criteria. We included studies that met the following inclusion criteria: (1) students receiving medical education, regardless of gender, age, grade, ethnicity, nationality, and educational background; (2) comparisons of six novel teaching methods with LBL; (3) literature including the outcome measurements of medical learning; (4) RCTs and (5) English publication. The exclusion criteria were as follows: (1) duplicated publications; (2) studies not using one major strategy and instead two or more methods in the same course; (3) curricula less than 10 studious hours; (4) unavailability of complete texts or reliable data; (5) enrollment of students specializing in nursing, pharmacy, or veterinary medicine and (6) reviews, case reports, conference abstracts and meta-analyses. Studies deemed ineligible by both authors were excluded, and any disagreements were resolved through team negotiation to reach a consensus.

Outcome measures and data extraction

The primary outcome focused on the efficacy of various teaching methods on improving medical students' academic performance, which was measured by theoretical test scores and experimental or practical test scores. Additionally, the secondary outcome aimed at students' satisfaction with the different teaching methods, as indicated by the satisfaction scores.

The key information extracted from all eligible studies were as follows: the name of the first author, year of publication, the characteristics of the students, the sample size, teaching methods employed in the intervention and control groups, curriculum, the sources of potential bias, and the outcome measures. This process was conducted independently by two authors (SLZ and SJR) using electronic Excel spreadsheets. A third author (DMZ) subsequently crosschecked the extracted data to ensure accuracy, resolving any discrepancies through consensus. Furthermore, the missing data were addressed using multiple imputation by chained equation (MICE) using the MICE package in R software [32], as multiple imputation techniques with a missing at random assumption tends to yield more unbiased results as well as more accurately estimated standard errors and confidence intervals [33].

Quality assessment of included studies

Two authors (SLZ and SJR) used the Cochrane Collaboration's risk of bias V.2.0 tool (RoB2) to assess the following biases of the included articles: (1) bias arising from the randomization process; (2) bias due to deviations from intended interventions; (3) bias due to missing outcome data; (4) bias in the measurement of the outcome; (5) bias in selection of the reported result and (6) overall bias [34]. Each item was classified as high risk, low risk or some concern. After the statistical analysis, the graph was generated and refined using GraphPad Prism 10 software (GraphPad, San Diego, CA, USA).

Statistical analyses

Pairwise meta-analysis

The direct evidence was analyzed through pairwise meta-analyses utilizing a random-effects model in Stata 14 software (StataCorp LLC, College Station, TX, USA). Given that all outcome measurements were continuous, the standardized mean differences (SMDs) were chosen as the effect size measure, along with 95% confidence intervals (CIs) due to the utilization of diverse rating scales in the included studies [35]. Statistical heterogeneity in each pairwise comparison was assessed with the p value of the Q-test, I^2 statistic and between-study variance (τ^2).

Network meta-analysis

This NMA was conducted to estimate the ranking of six novel teaching strategies in medical classes by combining direct and indirect comparisons. The three outcomes were summarized as SMDs along with 95% CIs and were analyzed independently. A random-effects model was utilized to obtain more conservative conclusions regardless of heterogeneity [36]. Network plots were generated in Stata 14 software. Additionally, league tables and forest plots were generated to illustrate the effect sizes for effectiveness across all possible comparisons of teaching strategies. Moreover, the surface under the cumulative ranking curve (SUCRA) serves as a tool to evaluate the probability of ranking each teaching strategy. Simultaneously, a bar graph is utilized to visually present the SUCRA probabilities associated with distinct teaching strategies, facilitating a comparative analysis of their impacts on three outcome indicators. The node-splitting method was applied to detect any inconsistencies between direct and indirect comparisons [37, 38].

Meta-regression, subgroup analyses

Meta-regressions were performed to address potential heterogeneity. Meta-regression evaluated the influence of the following potential factors: (1) publication year;

(2) region; (3) mean age; (4) gender (% female); (5) sample size; (6) risk of bias; (7) education background; (8) major and (9) curricula. Additionally, we conducted subgroup analyses based on the difference of the region, curricula, and educational background.

Sensitivity analyses

To ascertain the reliability of the findings, sensitivity analyses were performed for each outcome by omitting trials deemed to have a high risk of bias, those with a small sample size ($n < 30$), and those with missing data. The robustness of the conclusion was determined by assessing the consistency of the results of the NMA effect size (SMDs and 95% CIs) and SUCRA probabilities before and after conducting sensitivity analyses.

Publication bias and grade of evidence

We used a comparison-adjusted funnel plot and Egger's test to detect the presence of potential publication bias [39]. A p-value > 0.05 suggested no significant publication bias among the included studies. We deployed the fill and trim method to estimate the number of missing studies and evaluate the impact of publication bias on the results.

Additionally, the quality of evidence for the primary outcome was graded using the Confidence In Network Meta-Analysis (CINeMA) software [40], which characterizes the quality of a body of evidence based on (1) within-study bias; (2) reporting bias; (3) indirectness; (4) imprecision; (5) heterogeneity and (6) incoherence for network estimates [41]. We postulated a significant threshold for SMDs to be ± 0.2 in terms of imprecision. Based on this threshold, the quality of evidence will be categorized into four levels: high, moderate, low, and very low.

Results

Characteristics of included studies

After systematic searches and elimination of duplicates, a total of 7138 potential studies were identified for screening. We then screened these studies for eligibility based on their titles and abstracts and excluded 6,757 of them, of which 381 studies remained. 301 articles were excluded after assessing the full text for various reasons. Ultimately, 80 articles met the predetermined inclusion and exclusion criteria and were selected for inclusion in the NMA (Fig. 1). The references for all included studies are provided in the supplemental appendix 4.

Supplemental appendix 5 summarizes the detailed characteristics of the included studies. This review comprised 80 RCTs involving 6,180 students participating in medical education programs. In the studies analyzed, most students belonged to the clinical medicine field (64/80, 80%), with some also specializing in oral medicine, traditional Chinese medicine, and other related disciplines. In terms of educational background, 86.2% of students (5328/6180) were enrolled at the undergraduate level, as indicated by 54 out of the 80 studies. Outcome assessments varied among the studies, with 58 trials focusing on theoretical test scores, 38 on experimental or practical test scores, and 13 on students' satisfaction scores.

Quality of included studies

Utilizing RoB2 for quality assessment, Fig. 2 provides a summary of the evaluated outcomes from the 80 included RCTs. Of these studies, 13 (16.25%) were classified as having a high risk of bias, 37 (46.25%) were categorized as having some concerns, and 30 (37.50%) were deemed to have a low risk of bias.

In the context of the randomization process, 34 studies (42.50%) were identified as low risk of bias by employing the correct method of random sequence generation, while 37 articles (46.25%) raised some concern. Besides, 79 (98.75%) and 76 (95%) studies were assessed as having a low risk of bias concerning deviations from intended interventions and the measurement of outcomes, respectively. Moreover, all studies included outcomes for all participants, resulting in a low risk of bias assessment for missing outcome data across all studies. Considering the nature of medical education research trials, where pre-registration and protocols were not obligatory [42]. Thus, the bias related to the selection of the reported result may not be applicable. Detailed assessments of all five domains and the overall bias of each study were provided in the supplementary appendix 6.

Pairwise *meta*-analyses

In terms of the effectiveness of theoretical test scores, most novel teaching strategies, including BOPPPS, CBL, PBL, TBL, and SBL, demonstrated superior efficacy compared to LBL. Regarding experimental or practical test scores, BOPPPS, FC, TBL, and SBL were identified as more effective than LBL. Similarly, for students' satisfaction scores, BOPPPS, FC, PBL, and SBL were more effective than LBL. In summary, when compared to LBL, only BOPPPS and SBL exhibited significant differences across all three outcome indicators. Supplementary appendix 7 displays detailed outcomes of the other pairwise meta-analyses.

Network *meta*-analyses

The theoretical test scores

Among the 80 studies, 58 studies with 5,427 students reported theoretical test scores. This NMA systematically

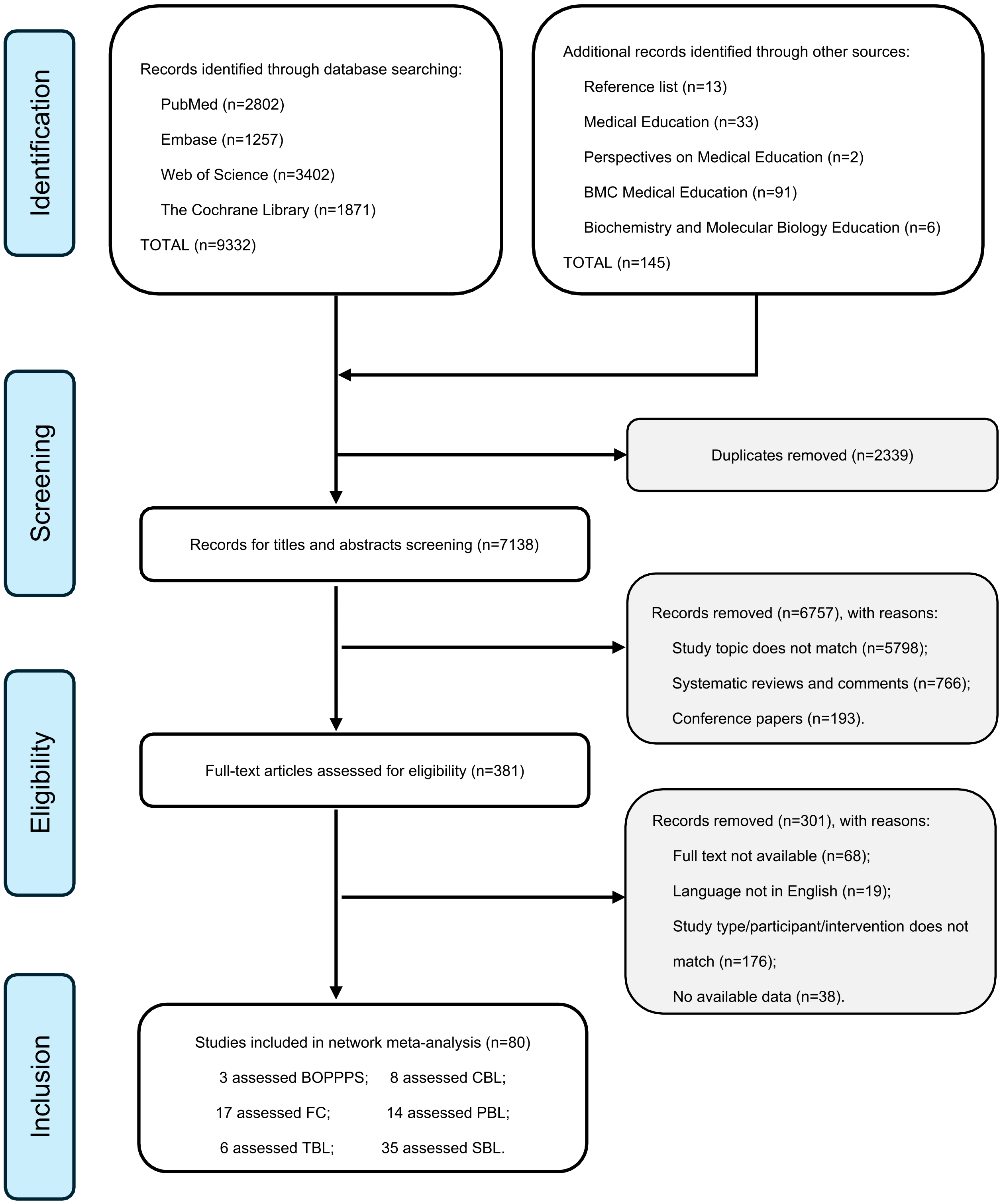

Fig. 1 PRISMA flow chart of study selection

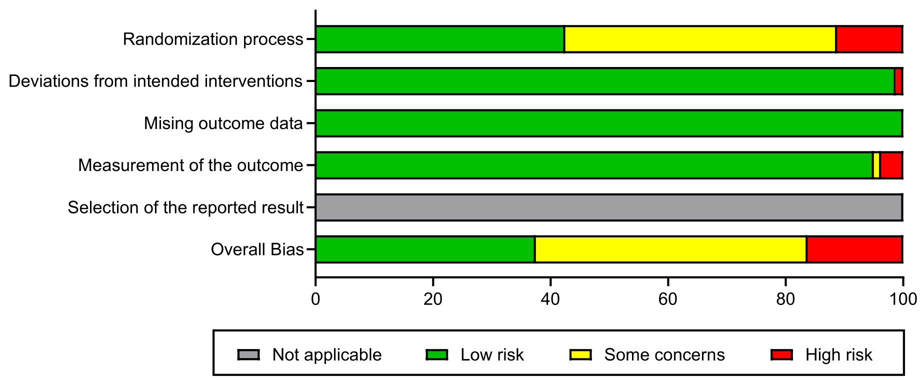

Fig. 2 Risk assessment of bias using the RoB2. Risk of bias items of all included studies are indicated as the percentages. Gray = not applicable, green = low risk of bias, yellow = some concerns, red = high risk of bias

evaluated the effects of BOPPPS ($n=3$), CBL ($n=7$), FC ($n=16$), PBL ($n=10$), TBL ($n=6$), and SBL ($n=16$). The network diagram of all detailed comparisons is presented in Fig. 3a.

The SMD values and 95% CI derived from NMA are illustrated in the upper right quadrant of Fig. 4 and are arranged in order in the forest plot of supplementary appendix 8A. Theoretical test scores were significantly lower in students who were taught using LBL teaching strategies compared to those who engaged with 4 novel strategies, including CBL (−1.19, 95% CI (−0.49 to −1.90)), PBL (−0.71, 95% CI (−0.18 to −1.25)), SBL (−0.69, 95% CI (−0.26 to −1.12)), FC (−0.69, 95% CI (−0.22 to −1.17)). However, the 95% CI of comparisons between other teaching strategies crossed zero, meaning that no significant difference was observed among the remaining novel teaching strategies. The results of the SUCRA rankings and probability values, as displayed in the supplemental appendix 9, suggest that CBL is the most likely to enhance theoretical test scores in medical education (probability, 89.4%).

The experimental or practical test scores

A total of 41 studies involving 3,301 students reported this indicator. Methods of BOPPPS ($n=2$), CBL ($n=1$), FC ($n=3$), PBL ($n=4$), TBL ($n=2$) and SBL ($n=29$), were included in this NMA. Details of other comparisons are shown in the network diagram of Fig. 3b.

The lower left part of Fig. 4 and the forest plot of supplementary appendix 8B displayed the specific SMD values and 95% CI generated by NMA. Students who used PBL or SBL strategies achieved significantly higher scores in experimental or practical tests compared to those using LBL strategies, with SMD values of 3.37 (95% CI, 0.18 to 1.25) for PBL and 0.69 (95% CI, 0.26 to 1.12) for SBL. It is noteworthy that no significant differences were observed in indirect comparisons among novel teaching strategies. The SUCRA ranking and probability

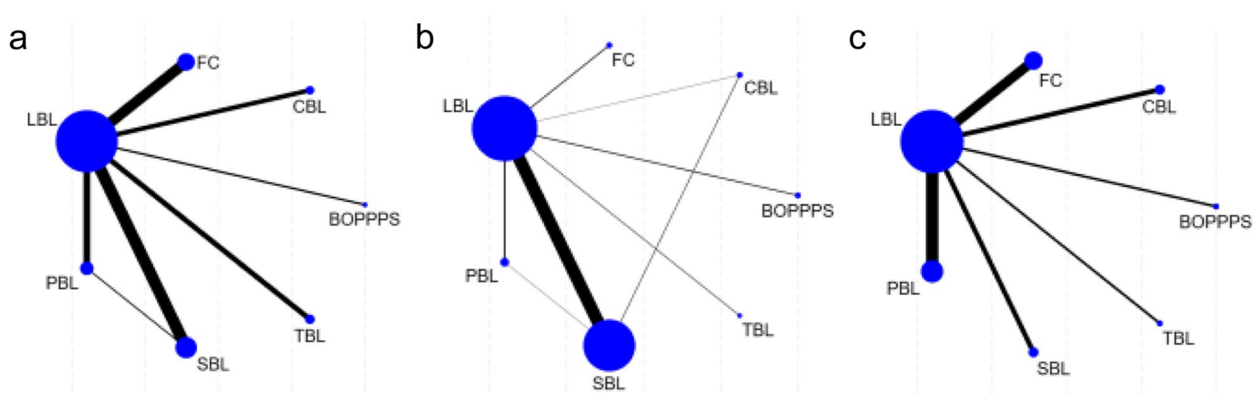

Fig. 3 Network of eligible comparisons for each outcome in the Bayesian network meta-analysis. (**a**) Theoretical test scores; (**b**) Experimental or practical test scores; (**c**) Students' satisfaction scores. BOPPPS, bridge-in, objective, pre-assessment, participatory learning, post-assessment, and summary; CBL, case-based learning; FC, flipped classroom; LBL, lecture-based learning; PBL, problem-based learning; SBL, simulation-based learning; TBL, team-based learning

The theoretical test scores

The experimental or practical test scores

CBL	−0.61 (−1.87 to 0.66)	−0.48 (−1.36 to 0.40)	−0.50 (−1.35 to 0.35)	−0.50 (−1.33 to 0.32)	−0.69 (−1.65 to 0.27)	**<u>−1.19 (−1.90 to −0.49)</u>**
−0.26 (−4.14 to 3.61)	BOPPPS	0.13 (−1.05 to 1.31)	0.11 (−1.05 to 1.26)	0.10 (−1.03 to 1.24)	−0.08 (−1.32 to 1.16)	−0.59 (−1.64 to 0.47)
−2.68 (−6.17 to 0.81)	−2.41 (−5.85 to 1.03)	PBL	−0.02 (−0.74 to 0.70)	−0.02 (−0.67 to 0.62)	−0.21 (−1.06 to 0.64)	**<u>−0.71 (−1.25 to −0.18)</u>**
−0.37 (−4.25 to 3.51)	−0.10 (−3.91 to 3.70)	2.31 (−1.13 to 5.75)	FC	−0.00 (−0.65 to 0.64)	−0.19 (−1.00 to 0.62)	**<u>−0.69 (−1.17 to −0.22)</u>**
−0.46 (−3.22 to 2.29)	−0.20 (−3.00 to 2.61)	2.22 (−0.01 to 4.44)	−0.09 (−2.90 to 2.72)	SBL	−0.19 (−0.97 to 0.60)	**<u>−0.69 (−1.12 to −0.26)</u>**
−0.47 (−4.80 to 3.87)	−0.20 (−4.48 to 4.07)	2.21 (−1.74 to 6.17)	−0.10 (−4.38 to 4.18)	−0.00 (−3.42 to 3.41)	TBL	−0.50 (−1.16 to 0.15)
0.69 (−2.10 to 3.48)	0.96 (−1.74 to 3.65)	**<u>3.37 (1.23 to 5.51)</u>**	1.06 (−1.63 to 3.76)	**<u>1.15 (0.36 to 1.95)</u>**	1.16 (−2.16 to 4.48)	LBL

Fig. 4 The results of Network meta-analysis for primary outcomes. Standard mean differences (SMDs) of the theoretical test scores (upper triangle) and the experimental or practical test scores (lower triangle). Data with SMDs represent the comparison of the row-defining method versus the column-defining method. Data in parentheses are the 95% confidence intervals. Methods are ranked according to their ranks of the probability of best in the surface under the cumulative ranking probabilities analysis (SUCRA) for starting with the best efficacy at the theoretical test scores. SMDs more than zero favor the column-defining method. Significant results are highlighted in bold, underline, and background fill. BOPPPS, bridge-in, objective, pre-assessment, participatory learning, post-assessment, and summary; CBL, case-based learning; FC, flipped classroom; LBL, lecture-based learning; PBL, problem-based learning; SBL, simulation-based learning; TBL, team-based learning

values in the supplementary appendix 9 indicated that PBL (probability, 93.3%) was the most likely method to improve experimental or practical test scores and operational skills.

The students' satisfaction score

A comprehensive analysis of 13 studies encompassing 849 students reported the students' satisfaction scores, thereby reflecting their students' subjective evaluations and attitudes toward various teaching methods. Methods of BOPPPS ($n=1$), CBL ($n=2$), FC ($n=4$), PBL ($n=3$), TBL ($n=1$) and SBL ($n=2$), were included in this NMA. The network diagram of all detailed comparisons is shown in Fig. 3c.

As represented in the supplemental appendix 8C and 10, the students' satisfaction scores were significantly higher in students learning with SBL strategy than in those students learning with PBL (1.62, 95% CI (0.01 to 3.22)) and TBL (2.77, 95% CI (0.43 to 5.11)). Additionally, other three novel strategies, including SBL (2.64, 95% CI (1.28 to 4.00)), FC (1.34, 95% CI (0.40 to 2.29)) and PBL (1.02, 95% CI (0.17 to 1.88)) showed better performance in enhancing students' satisfaction scores than LBL methods. These findings are consistent with the pair-wise meta-analyses. Additionally, the SUCRA analyses, as detailed in the supplementary appendix 9, showed that there was a high probability (96.2) that SBL would most significantly enhance student satisfaction scores and subjective assessments.

Subgroup analyses

Considering the importance of regional factors, curricular characteristics, and educational backgrounds, we conducted subgroup analyses to formulate refined and personalized teaching programs. Notably, PBL was found to be particularly effective in enhancing theoretical test scores in developing countries with a probability of 86.6%, as well as in basic courses with a probability of 78.3%. Besides, CBL emerged as the most effective method for improving proficiency in clinical course knowledge with a probability of 97.7% and demonstrated superior performance among students regardless of their educational backgrounds. Additionally, PBL remained the optimum approach for enhancing operational skills across all subgroups. Other detailed outcomes of subgroup analyses were displayed in the supplementary appendix 11. It was worth noting that due to the limited number of studies available, further subgroup analyses could not be conducted.

Sensitivity analyses

In the supplemental appendix 12, a few statistically significant variations in SMD effect sizes were observed. As shown in the supplemental appendix 13, the highest-ranked teaching strategies in SUCRA did not change, and the SUCRA probabilities of the remaining strategies remained relatively stable. However, SBL in theoretical test scores rankings notably shifted after excluding trials with small sample sizes, mirroring the changes in SMD values. This suggests that the previously unadjusted outcomes may be affected by small sample effects related to SBL. Collectively, sensitivity analyses indicated that the results of the NMA are generally robust in identifying the most effective method.

Evaluation of heterogeneity and *meta*-regression

As presented in supplemental appendix 14, the global I^2 values were 92.1% for theoretical test scores, 97.9% for experimental or practical test scores and 87.2% for students' satisfaction scores, indicating a high degree of heterogeneity across studies for all three indices ($I^2 > 50\%$). As presented in the supplemental appendix 15, network meta-regression showed most modifiers did not significantly affect the improved outcome of novel interventions in these three indices.

Evaluation of inconsistency

In the global inconsistency assessment, no statistically significant differences were observed between the inconsistency and consistency models for primary outcomes (supplemental appendix 16A). Additionally, the evaluation of inconsistency in the network of students' satisfaction scores is not required. Furthermore, tests of loop inconsistency and local inconsistency from the node-splitting model showed no inconsistent loops and no significant differences between any comparisons for the primary outcomes (supplemental appendix 16B and 16C).

Publication *bias* and grade of evidence

The result of Egger regression and comparison-adjusted funnel plots suggested that potential publication bias was found in the theoretical test scores (supplemental appendix 17A, $p = 0.002$) and experimental or practical test scores (supplemental appendix 17B, $p < 0.000$). However, no such bias was detected in students' satisfaction scores (supplemental appendix 17C, $p = 0.741$). One study with an abnormal SMD was identified and excluded, and an adjusted funnel plot was generated again (supplemental appendix 17D, $p = 0.022$). Subsequently, the fill and trim method was applied to assess the impact of publication bias on the robustness of the findings. Following the inclusion of 13 virtual studies, the adjusted SMD effect changed from 0.73 (95% CI, 0.52 to 0.93) to 1.47 (95% CI, 1.16 to 1.86), indicating a substantial improvement. After adding 16 virtual studies, the SMD effect of novel teaching strategies compared to LBL turned from 1.21 (95% CI, 0.85 to 1.57) to 1.30 (95% CI, 0.88 to 1.90), both displaying statistical differences in terms of experimental or practical test scores. Notably, the results remained consistent, suggesting that publication bias may not compromise the reliability of the network effect. Based on the CINeMA evaluation, it was determined that all 21 comparisons across the three indexes were rated as "very low". The detailed assessment of the six specific items is available in the supplemental appendix 18.

Discussion

Currently, advancements in computer technology and reforms in the healthcare service system have rendered medical students educated under traditional frameworks insufficiently prepared to meet the evolving demands of public healthcare [43]. Various novel teaching strategies have been widely adopted globally and achieved promising teaching efficiency. However, the absence of direct comparative evidence has left uncertainties regarding the most effective teaching strategies for enhancing learning outcomes among medical students. The NMA method is more intuitive than traditional pairwise meta-analysis and can bring more valuable information [44]. Therefore, we conducted this NMA to evaluate the effectiveness of teaching methods on performance and students' satisfaction with teaching methods in terms of theoretical test scores, experimental or practical test scores, and students' satisfaction scores. By aggregating all accessible evidence from 80 RCTs involving 6,180 medical students, the results indicated that CBL and PBL emerged as the most effective teaching approaches for enhancing the learning quality and performance of medical students, while SBL has been identified as providing a more effective learning experience throughout the educational process.

The theoretical test scores, serving as the primary outcome measure, directly reflect the efficacy of various teaching strategies on student performance. In evaluating the influence of medical education on theoretical test scores, CBL was identified as the most effective teaching strategy, with a probability of 89.4%. A previous pairwise meta-analysis demonstrated that the implementation of CBL enhanced the academic performance and case analysis skills of medical students [45]. Other prior research indicated that the efficacy of the CBL in enhancing medical students' learning outcomes stems from its ability to stimulate and promote their critical thinking abilities [46, 47]. Interestingly, our subgroup analysis of curricula showed that CBL was more effective for clinical knowledge learning in enhancing theoretical test scores and the application of clinical cases brings medical students into the context of practical problems, which enables students to exert their active learning ability and improve their understanding of theoretical knowledge [48]. Moreover, regardless of whether at the undergraduate or graduate level, the efficacy of CBL in improving theoretical test scores remains consistently superior. This finding underscores the relevance of CBL across all educational levels and highlights the importance of analyzing practical cases for the acquisition of knowledge in the medical field. In addition, we found that the PBL significantly improved theoretical test scores than the traditional education strategy (SMD = 0.71, 95% CI (0.18 to 1.25)), suggesting that students seem to learn better under the problematic guideline. This was consistent with other meta-analyses, which also demonstrated significantly higher theoretical scores and examination pass rates after applying PBL in class teaching [23, 49–51]. However, another meta-analysis from Zheng QM et al. failed to find positive effects of PBL in learning theoretical knowledge compared with LBL [52].

The experimental or practical test scores, which assess students' proficiency in fundamental medical experiments and clinical skills, serve as a direct indicator of the efficacy of hands-on learning. The results of SUCRA showed that PBL was the best strategy to improve medical students' experimental or practical test scores and operation abilities. A systematic review focusing on Chinese standardized residency training found that PBL was more successful in the mastery of operational skills, analysis and diagnosis of cases, and overall capacity [53]. Additionally, Liu CX et al. illustrated increased clinical skills assessment scores and comprehensive ability scores in the clinical curriculum learning environment [54]. NMA also proved that PBL can improve the scores in theoretical tests, experimental tests, and students' satisfaction at the same time, which indicates the comprehensiveness of this teaching strategy. Moreover, subgroup analyses found that PBL was the most effective strategy for enhancing theoretical test scores in basic medicine curricula. Our findings from subgroup analyses indicate that PBL is implemented more effectively in developing countries. This phenomenon may be attributed to the relatively straightforward instructional methodologies associated with PBL, as well as its earlier introduction and subsequent rise in popularity within these regions [55]. Conversely, in developed nations, SBL demonstrates greater efficacy in enhancing theoretical performance, which is closely related to the rapid development of the internet and virtual simulation technology [56]. Nevertheless, there existed variability in findings within clinical medicine curricula: PBL continued to demonstrate superior efficacy in enhancing experimental or practical test scores, whereas CBL was identified as the optimal strategy. However, the combination of CBL and PBL also shows an obvious learning improvement effect in other RCT studies, which guides students to better apply knowledge and enrich their experience from solving problems [20, 57]. This indicated that in clinical teaching settings, educators can employ CBL combined with PBL approaches and carry out targeted teaching in both theory and experiment of primary outcomes to maximize the learning quality and academic performance of students.

Students' satisfaction scores reflect students' subjective evaluation and attitude towards various teaching methods. SBL and FC, as contemporary computer-based instructional approaches, performed well in improving students' satisfaction and subjective evaluation. By simulating real medical situations, SBL facilitates experiential learning, thereby enhancing students' practical operation ability and problem-solving capabilities, and heightening students' enthusiasm and proactive engagement in medical education [58]. In addition, it is worth noting that there are significant differences between SBL and PBL (1.62, 95% CI (0.01 to 3.22)), or TBL (2.77, 95% CI (0.43 to 5.11)) in improving students' satisfaction scores. However, another network meta-analysis demonstrated that TBL could be the most effective strategy for enhancing theoretical test and satisfaction scores in pharmacology classes [9]. This discrepancy could be attributed to variations in research objectives and participant demographics. Additionally, the incorporation of SBL as a new strategy in our study may have influenced the outcomes. Furthermore, the limited number of studies included in the assessment of students' satisfaction scores and more application of SBL in nursing education instead of medical education underscores the necessity for future research to elucidate the impact of teaching modes on student satisfaction [59–62].

This study summarizes and strengthens available evidence supporting novel teaching strategies in the current scholarly literature of medical education. To our knowledge, there were a few systematic reviews and NMA evaluating the effects of novel teaching methods on specific or majors and curriculums, such as nursing [63] and pharmacology [9]. However, this present study was the first systematic review and NMA to investigate the effects of novel teaching strategies on so many basic and clinical medicine courses, which filled the gap in the field of medical education. The NMA results provide a ranking of mesh fixation for seven teaching strategies to instruct curriculum designers and educators, supporting widespread dissemination and implementation of novel instruction techniques. Besides, to make sure that all relevant studies have been included with limited selection bias, two authors performed the study selection, data extraction and quality assessment independently. Furthermore, we conducted meta-regression, sensitivity analyses, and fill and trim method to verify the robustness of our results. Subgroup analyses also were performed to explore more refined teaching programs for specific students.

Several limitations should also be noted. First, only six single novel teaching strategies are evaluated in this NMA, and other modes and various combinations of teaching methods are excluded from this study. The complexity arising from the integration of diverse teaching strategies may hinder the execution of network meta-analysis. However, this NMA can enhance the identification of effective teaching strategies and facilitate the arrangement of teaching courses. Secondly, the characteristics of the instructional methodology preclude the possibility of blinding in both students and instructors. As a result, students may alter their behaviors when they know they are being studied under various teaching strategies, which subsequently influences the reliability of evidence in RCTs. This limitation is an inevitable, yet critical deficiency presented in all the original studies contributing to this meta-analysis. Since pre-registration of the protocol is not required for research in the field of education, the bias of selective reporting of results in evaluating the quality of the literature does not apply, which will have an impact on the quality assessment of the included literature. Thirdly, the scope of this study was limited to English-language publications, potentially excluding trials with negative results that may be present in extensive national databases like those in Chinese literature [64]. This constraint could account for the potential publication bias observed in the primary outcome measurements presented in the supplemental appendix 17, potentially leading to the risk of overestimating the effectiveness of teaching strategies. Hence, more rigorous, and high certainty RCTs are needed to verify the results. Fourthly, varying baseline characteristics of the students, the expansive design framework, and the disparity in the expertise levels of the teachers involved in the study may cause large heterogeneity to some extent [65]. Furthermore, NMA is not the same as a direct comparison and introduces the additional risk of bias, especially in cases where there are fewer direct comparisons between the novel teaching strategies in our NMA, which may result in imprecision. The presence of significant heterogeneity and imprecision within the data substantially diminishes the quality of evidence, resulting in decreased result accuracy displayed in the supplemental appendix 18. Lastly, this study does not fully capture other important qualities and skills of medical students in the "types of outcomes" section, such as their ability to analyze cases, social and communication skills, problem-solving and self-learning abilities, and subjective enthusiasm. Future research with direct comparisons among novel teaching strategies should be conducted to explore optimal educational approaches for medical students.

Conclusion

Among the six novel teaching strategies, CBL and PBL may be more effective in enhancing the educational quality and efficacy of medical students. Furthermore, SBL has been identified as providing a more effective learning experience throughout the educational process. This comprehensive evidence provides new insights for forthcoming medical education guidelines. However, the difference among these novel teaching strategies appears to be minimal. Given that the direct comparisons between novel teaching strategies were few discussed, future head-to-head studies are needed to clarify the distinctions among these novel teaching strategies.

Abbreviations

BOPPPS	Bridge-in, objective, preassessment, participatory learning, post-assessment, and summary
CBL	Case-based learning
FC	Flipped classrooms
LBL	Lecture-based learning
PBL	Problem-based learning
SBL	Simulation-based learning
TBL	Team-based learning
SMD	Standard mean difference
CI	Confidence interval
NMA	Network meta-analysis
SUCRA	Surface under the cumulative ranking probabilities analysis
RoB2	Version 2 of risk of bias tool
PICO	Population, intervention, comparison, and outcome
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
RCTs	Randomized controlled trials

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-024-06291-4.

Additional file 1. Supplemental Appendix.

Additional file 2. PRISMA 2020 Checklist.

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Authors' contributions

Shuai-Long Zhang: Methodology, Investigation, Writing-original draft, Formal analysis. Si-Jing Ren: Visualization, Software, Writing-original draft. Dong-Mei Zhu: Conceptualization, Methodology, Investigation, Resources,

Writing-review & editing. Tian-Yao Liu: Methodology, Investigation. Lian Wang: Methodology, Investigation. Jing-Hui Zhao: Methodology, Investigation. Xiao-Tang Fan: Conceptualization, Funding acquisition, Writing-review & editing, Supervision. Hong Gong: Conceptualization, Project administration, Funding acquisition, Writing-review & editing, Supervision.

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Data availability
The datasets analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
No formal research ethics approval is required because this study is a meta-analysis based on published data.

Consent for publication
Written informed consent for publication was obtained from all participants.

Competing interests
The authors declare no competing interests.

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