BMC Medical Education

RESEARCH

Open Access

A practice and exploration of blended learning in medical morphology during the post-COVID-19 pandemic era

Qinlai Liu[1,2†], Na Yuan[1†], Yongan Wang[3], Beibei Sun[1], Leiying Yang[1], Zhaopeng Wang[1], Chen Fang[1], Wenping Sun[1], Baihua Luo[4], Yaling Liu[1], Xin Liu[1] and Li Ge[1,2*]

Abstract

Background Since 2021, the prevention and control of the coronavirus disease 2019 epidemic has been normalized. However, considering the high density of students and the potential for epidemic relapse, our medical morphological teaching team established a novel blended learning mode with mainly offline teaching in the general sections and blend learning in systematic sections. Specifically, this study sought to improve the teaching quality of the two courses of "Histology and Embryology" and "Pathology", and lay a solid foundation for clinical medical undergraduates to learn medical courses well in the future.

Methods In the Spring 2021 semester, two classes from the Class of 2019 and two classes from the Class of 2020 were randomly selected as the intervention groups, to carry out blended learning of "Histology and Embryology", and "Pathology", respectively. Meanwhile, four parallel classes were randomly selected as control groups to carry out completely traditional offline teaching. The blended learning was based on outcome-based education concepts and used small private online courses from the "Xuexi Tong" (Century Superstar Information Technology Development Co., Ltd., Beijing) platform. In the theory class, case-based learning following a self-designed P-C-P-E-S-E (Pre-class-Case-Problem-Expansion-Summary-Expansion) teaching sequence was implemented. In the experimental class, a virtual digital platform with flipped classroom learning was integrated.

Results Both teaching satisfaction and students' scores were found to be significantly greater in the intervention group than in the control group. Furthermore, the intervention group also effectively surpassed the control group in terms of students' comprehensive abilities such as drawing, scientific research, participating in competitions, forensic case analysis, and so on.

Conclusion Our novel blended learning approach strengthened the communication between teachers and students, obviously improved students' self-directed learning abilities, and finally achieved the purpose of improving the comprehensive abilities of students. This mode is suited for the post-epidemic era and future variable environments. It also has substantial promotional instructive modeling value.

†Qinlai Liu and Na Yuan contributed equally to this work.

*Correspondence:
Li Ge
juliagl@126.com

Full list of author information is available at the end of the article

Clinical trial registration Not applicable.

Keywords Blended learning mode, Post-pandemic era, Histology and embryology, Pathology, Case-based teaching, Outcome-based education

Backgroud

The outbreak of coronavirus disease 2019 (COVID-19) brought about an unprecedented impact on education [1]. Prevention and control measures undertaken in response to the epidemic spurred progress and innovation across all sectors of Chinese society [2], particularly in terms of increasing the efficiency of higher education's teaching and management and fostering innovation in the standards and value assessment system of personnel training [3]. Since March 2021, China's epidemic-prevention and -control measures have transitioned into a remission period, which is now known as the "post-epidemic era" [4]. However, universities and colleges are densely populated areas, and, despite overall case remission, recurring outbreaks and new explosions of positive cases have occurred. Meanwhile, the widespread adoption of wireless fidelity and online teaching systems or platforms has significantly propelled the informatization of China's higher education [5, 6]. To achieve better epidemic prevention and control, Chinese college educators have increasingly adopted blended learning, which has yielded unexpectedly positive teaching outcomes [7].

The process of learning medicine is much like constructing a skyscraper, where the curriculum system is composed of basic, bridge, and clinical courses, respectively. Both the "Histology and Embryology" and "Pathology" courses belong to the category of medical morphology, serving as crucial foundational and bridge courses in the clinical medicine curriculum. Amid the COVID-19 epidemic, our teaching team established an innovative online teaching model in response to the situation of students' studying at home [8], which had a relatively good teaching effect. Entering the post-epidemic era, this team promptly adapted and enhanced the teaching plan, ushering in a novel blended learning approach based on the outcome-based education (OBE) concepts [9].

Blended learning encompasses a diverse range of instructional methods, including traditional face-to-face learning, self-directed learning, asynchronous or synchronous online education, multidimensional cognitive exercises, interactive flipped classroom learning, group discussions and lectures, among others [10–14]. This study employs a novel blended learning model with case-based and small private online courses (SPOC) [15]. We implemented a self-designed P-C-P-E-S-E (Pre-class-Case-Problem-Expansion-Summary-Expansion) teaching sequence in both theoretical and experimental courses. Additionally, we endeavored to implement "integrated lectures", enabling students to form a comprehensive understanding of medicine from an early stage [16]. Concurrently, we involved exceptional undergraduates in our research projects, granting them access to scientific inquiries as early as possible. This approach aimed to kindle students' enthusiasm for learning and foster their problem-solving abilities. The "Histology and Embryology" and "Pathology" courses were integrated to the discipline of medical morphology, with the goal of enabling medical students to better conceptualize, execute, and assess processes. With this study, we aspired to furnish instructive models for future teaching at Shandong First Medical University and other medical institutions in the post-epidemic period.

Methods

Participants

In 2021, this study was conducted concurrently with undergraduates majoring in clinical medicine who were taking courses on "Pathology" (Class of 2019) or "Histology and Embryology" (Class of 2020). The intervention group of the Class of 2019 consisted of 111 students from Classes A and B, while the control group included 111 students from parallel Classes C and D. Meanwhile, from the Class of 2020, 91 students from Classes A and B composed the intervention group, while 92 students from Classes C and D constituted the control group. There were no significant differences in sex, age, or enrollment scores between the intervention and control groups.

Theoretical course teaching

Both the "Pathology" and "Histology and Embryology" courses provide 4 credits for graduation, with a total of 90 teaching hours each (Pathology: 50 theoretical hours/40 experimental hours; Histology and Embryology: 54 theoretical hours/36 experimental hours). One-fifth of the theoretical hours are allocated to online learning, while the remaining hours are conducted through offline teaching. The control group and the intervention group were treated equally in terms of teaching time arrangement. Our team adopted the OBE concept and reconstructed the curriculum based on our self-designed P-C-P-E-S-E teaching sequence (see Fig. 1). In this sequence, "P" represents the "Pre-class" section, during which students, under the guidance of teachers, study the SPOC provided by the "Xuexi Tong" platform and engage in integrated learning of "Pathology" and "Histology and Embryology" knowledge, as well as various tests. This part takes about 10–11 h. Additionally, "C-P-E-S" stands for the

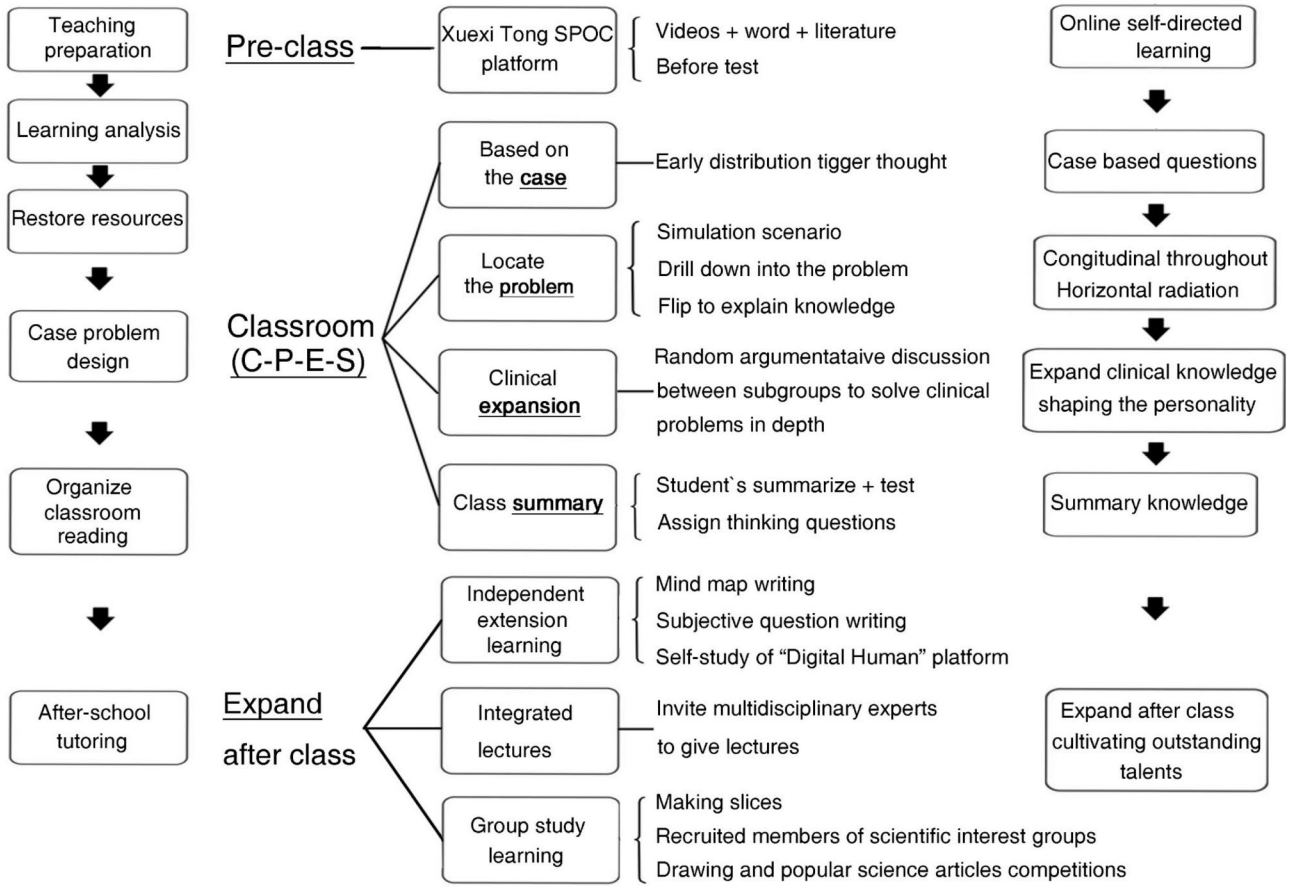

Fig. 1 Self-created P-C-P-E-S-E teaching sequence. At different stages (including pre-class, classroom and expasion after class), different teaching methods were adopted for the intervention group

"Case–Problem–Expansion–Summary" sequence in the intervention group's classroom activities, which accounts for 80 h. while the control group mainly follows the traditional teaching approach. The final "E" refers to the after-class expansion. This includes case analysis, subjective question writing, drawing, and the series of recorded integrated lectures uploaded in the data section. The time spent on these online activities varies depending on an individual's level of attention, interest, and after-class time arrangement, and it is approximately 15–20 h. Some students also participate in scientific research interest groups, forensic science outreach work, and various academic competitions, and the time required for these offline activities is uncertain, also around 15–20 h. This strategic allocation of content and time both inside and outside the classroom aims to better coordinate online and offline learning.

Pre class

Taking a peptic ulcer of the digestive system as an example, in advance, teachers provided preview hints regarding histology, pathology, clinical diagnosis, and other related learning aspects as an outline to guide 10 sub-groups to prepare for presentation and role-plays. In greater detail, areas of interest included the macroscopic (including gastroscopy) and microscopic observations, etiology, pathogenesis, clinicopathological associations, outcomes, complications, and distinctions between duodenal and gastric ulcers, and between benign and malignant ulcers, respectively. These preview demands and pregiven materials extended relatively beyond the requirements of the morphological course's syllabus. Students were also encouraged to conduct extensive literature searches and expand related learnings based on their individual interests. The assignments of each sub-group and an undiagnosed peptic ulcer case were released. Students could take advantage of their fragmentation time to freely watch the related relevant materials uploaded by the teacher in advance, engage in the group discussions and interact with teachers on the "Xuexi Tong" platform.

Teachers also provided the preview hints 2- weeks before class to the control group, requiring students to pre-study related contents independently online. However, no further pre-class learning tasks such as presentations, role-plays, or case analyses, were assigned to these students.

Finally, five related multiple-choice questions were released online to assess the effectiveness of students' pre-study in both groups.

In class (C-P-E-S)

After all participating students signed online, two sub-groups first performed their role-plays, and the representatives of other sub-groups made presentations in succession. Then, each sub-group posed some questions, and other students answered questions where appropriate. Subsequently, the teacher presented five questions related to clinical examination referring to the cases assigned beforehand, covering toipcs like diagnosis, gastroscopy and other basic tests, related treatments and prevention issues. A further open interactive question and answer (Q&A) session and a random argument session were held to foster productive interaction. Finally, each sub-group's performance were scored through the "Xuexi Tong" platform (see Supplementary Material S1), focusing on self-evaluation (10%), mutual evaluation (50%), and teacher's assessment (40%). After scoring, students were randomly selected to summarize the essence of the course, and several online multiple-choice questions were published as a summary test. Of note, the whole teaching process of the intervention group was videotaped for further use.

In the control group, teacher-led lectures were adopted as the primary teaching approach, students' attendance was recorded, and the arranged multiple-choice questions were answered in class.

After class (expansion)

Some experts from other disciplines, such as anatomy, immunology, psychology, and gastroenterology, were invited to deliver integrated lectures in the intelligent classroom to the intervention group (see Supplementary Material S2), and the whole process were recorded. Several expanded assignments were published. Another peptic ulcer case was then assigned via the "Xuexi Tong" platform, and students were required to conduct an independent analysis, with online evaluations and the standard answers posted 1 week later. A mind map of this chapter was required to be drawn and uploaded to the "Xuexi Tong" platform according to the scoring criteria (Supplementary Material S3). Online chapter tests were also required to be completed in timely fashion. In addtion, an open-ended subjective question to be completed after class was assigned online, covering topics as "What do I know about the *Helicobacter pylori*?". Students could answer such questions in various dimensions and forms online. After an anonymous mutual evaluation, teachers revised the evaluation results based on the designated standard (see Supplementary Material S4).

For the control group, the tasks to be completed through the "Xuexi Tong" platform after class, included chapter tests, mind maps, open-ended subjective questions, and so on. Videos of the teaching process of the intervention group and integrated lecture videos were also uploaded online for these students to view, enabling them to complete self-directed learning conveniently. Any related errors will be discussed and corrected by the teacher team. Some videos will be subtitled in Chinese. For some obvious errors, corrections will be attached. For common mistakes, teachers will also provide explanations in class. This is to ensure the fairness of teaching resources between the intervention and control groups.

Experimental course teaching

Before class, related explanatory videos for all slices were recorded using screen-recording software and uploaded online to facilitate students' early self-study. During class, considering teachers' attention and guidance, students of both groups were exposed to small-scale teaching. There were micro-digital interactive systems available in the offline classroom, and each student's microscope field of view could be viewed by the whole class. For the intervention group, several cases were used for classroom education, and, after all of the slices were read, a student was selected at random to explain the slices of a random case, and a discussion and Q&A interactive session held thereafter. Finally, teachers provided a summary and an evaluation of the class (see Supplementary Material S5). Meanwhile, in the control group, the details of each slice were explained by the teacher, with students' independently observing thereafter. After class, all students of both groups completed picture- drawing assignments. Then, at the end of the semester, a test on independently reading slices was conducted. Considering that students only had limited time to operate microscopes and observe slices in the laboratory, they were encouraged to preview and review morphological knowledge online. To facilitate this review, the online Shandong First Medical University STEM Morphology System platform (https://sdfmu.humanyun.com) [17], which includes digital slices of human anatomy, histology, three-dimensional gross pathology, and histopathology, was used to support related self-directed learning. This platform is freely available on various electronic devices. Teachers also emphasized the combination and progressive learning of pathological and histological slices. To enhance test difficulty, histological and pathological slices were mixed together for testing on the final exam. Compared to students in the control group, students in the intervention group sought out more supplementary materials prior to class relatively actively due to experiencing relatively greater pressure, which increased their motivation. Data of the STEM Morphology System platform also showed

that the intervention group exhibited relatively greater engagement and more data visits.

Competitive learning

The morphological drawing contests, map-recognition contests and the outstanding popular science articles selection contests were organized at Shandong First Medical University. Relative outstanding works were recommended for provincial and national competitions. Excellent works and participants were offered additional one-on-one guidance by the teachers who gave classes.

Cultivation of scientific research literacy and practical ability

High-achieving students with a passion for scientific research from both the intervention and control groups were recruited to join scientific interest groups. To enhance their research skills, students who were recruited were required to complete weekly literature reviews and summary reports. In addition, related histological and pathological slices were produced for further observation and analysis. Some students interested in forensic medicine were allowed to participate in on-site autopsy investigations, making and observing slices for forensic cases analysis.

Statistical analysis

Students' final grade was determined by scores on a theoretical exam (60%), experimental exam (20%), and formative assessment (20%); of these, the formative assessment (100%) included attendance (5%), questions and case discussions (15%), drawing (20%), mind mapping and routine tests (chapter, midterm, pre-class and in-class tests) (20%), flipped classroom (20%) and subjective topics (20%). Students' performance after class was considered for potential bonus points. To ensure the teaching program is well-designed and to continuously optimize and improve the teaching process, the questionnaire surveys for both the intervention and control groups were conducted in the third and final weeks of the semester (first- test questionnaire and second- test questionnaire, respectively). These questionnaires covered specific topics, such as learning behaviors and related satisfaction.

SPSS® 25.0 statistical software (IBM Corporation, Armonk, NY, USA) was used to analyze the final theoretical or experimental scores of both the intervention and control groups. GraphPad Prism®5 (GraphPad Software Inc., La Jolla, CA, USA) was employed to generate corresponding histograms. Scores are presented as "mean ± standard deviation values". *T*- tests were performed to compare mean scores between the intervention and control groups. $P<0.05$ was considered statistically significant (with $P<0.01$ indicating high significance).

For questions containing Likert-scored or ranked data (which were assumed to be non-normally distributed), responses to the first- and second- test questionnaires were compared between students using the non-parametric Wilcoxon signed-rank tests. Spearman rank-order correlations were conducted to examine relationships between perceived learning preferences and measured outcomes' effectiveness. The mean of each effectiveness outcome, composed of all corresponding questionnaire items, was calculated. Spearman's rho (rs) coefficient and *P*- value are reported for significant correlations. The significance level was set at $P<0.05$. Demographic data were analyzed using descriptive statistics.

This project received the approval from the ethics committee of experimentation of the Shandong First Medical University (decision no. R202103100178), and all participants signed an informed consent form.

Results

Improved ability to apply theoretical knowledge

In the first questionnaire survey of the intervention group, we received 85 effective Histology and Embryology questionnaires and 106 effective Pathology questionnaires collected using "Questionnaire Star (Changsha, China)". As such, the effective rate was 94.55% ([85 + 106] / [91 + 111]). At the end of the teaching period, the intervention group submitted 88 valid Histology and Embryology questionnaires and 106 valid Pathology questionnaires as the second survey, with a resulting effective rate of 96.04% ([88 + 106] / [91 + 111]). Meanwhile, in the control group, responses to the first survey, resulted in an effective rate of 94.58% ([86 + 106] / [92 + 111]), while that for the second survey, was 96.59% ([88 + 107] / [92 + 111]). The specific survey results are displayed in Table 1, and the satisfaction survey results are shown in Fig. 2. In terms of the clarity of Pathology teaching objectives, the intervention group indicated the strong agreement value was 58.49% and the agreement value was 30.19%, whereas the control group reported corresponding values of 35.51% and 21.50%, respectively ($P=0.000$). When asked about the reasonableness of the arrangement for Pathology teaching, 51.89% responded "strongly agree" and 33.96% responded "agree" in the intervention group, while the corresponding percentages for the control group were 33.64% and 24.30%, respectively ($P=0.000$). In terms of overall satisfaction, students in the intervention group expressed greater levels of contentment, with 45.28% reporting strong agreement and 35.85% reporting agreement. In contrast, in the control group, 23.36% strongly agreed and 32.71% agreed, respectively ($P=0.000$). Similar trends were observed for Histology and Embryology. Also, according to the questionnaires, 82.35% of students studying Histology and Embryology (Fig. 3A) opted for the current blended

Table 1 Responses to the method's effectiveness of students from the intervention group in the questionnaires

Survey content	Course	Time order	*N*	SA (%)	A (%)	*N* (%)	D (%)	SD (%)	Mean	*P*
Accept and enjoy the experimental flipped classroom	His-Emb	first	85	41.18	25.88	22.35	5.88	4.71	3.93	0.001
		sec	88	61.36	28.41	9.09	1.14	0	4.50	0.001
	Pat	first	106	27.36	31.13	16.98	15.09	9.43	3.52	0.000
		sec	106	50.94	26.42	17.92	3.77	0.94	4.23	0.000
Accept and enjoy the flipped theory class	His-Emb	first	85	40.00	28.24	20.00	8.24	3.53	3.93	0.037
		sec	88	61.36	27.27	10.23	1.14	0	4.49	0.037
	Pat	first	106	25.47	27.36	17.92	22.64	6.60	3.42	0.000
		sec	106	54.72	18.87	20.75	4.72	0.94	4.22	0.000
Accept and enjoy the case based teaching	His-Emb	first	85	47.06	24.71	17.65	5.88	4.71	4.04	0.011
		sec	88	62.50	25.00	10.23	2.27	0	4.48	0.011
	Pat	first	106	40.57	26.42	20.75	2.26	0	3.95	0.000
		sec	106	76.42	19.81	3.77	0	0	4.73	0.000
Accept the combination teaching of His-Emb and Pathology	His-Emb	first	85	47.06	35.29	9.41	8.24	0	4.21	0.035
		sec	88	60.23	31.82	7.95	0	0	4.52	0.035
	Pat	first	106	58.49	24.53	12.26	4.72	0	4.37	0.001
		sec	106	77.36	17.92	4.72	0	0	4.73	0.001
Accept and attend the related discipline competition	His-Emb	first	85	36.47	23.53	20.00	15.29	4.71	3.72	0.001
		sec	88	55.68	23.86	17.05	3.41	0	4.32	0.001
	Pat	first	106	29.25	26.42	32.08	8.49	3.77	3.69	0.000
		sec	106	77.36	17.92	4.72	0	0	4.73	0.000
Accept and make the mind mapping	His-Emb	first	85	38.82	29.41	23.53	5.88	2.35	3.96	0.004
		sec	88	56.82	27.27	15.90	0	0	4.41	0.004
	Pat	first	106	31.13	27.35	33.02	6.60	1.89	3.79	0.000
		sec	106	79.25	10.38	10.38	0	0	4.69	0.000
Accept and write subjective topics	His-Emb	first	85	35.29	29.41	18.82	11.76	4.71	3.79	0.003
		sec	88	55.68	23.86	15.91	3.41	1.14	4.30	0.003
	Pat	first	106	28.30	29.25	30.19	9.43	2.83	3.71	0.000
		sec	106	66.04	13.21	19.81	0.94	0	4.44	0.000
Accept and view the virtual and real slices	His-Emb	first	85	38.82	27.06	20.00	11.76	2.35	3.88	0.000
		sec	88	68.18	25.00	6.82	0	0	4.61	0.000
	Pat	first	106	28.30	29.25	30.19	9.43	2.83	3.79	0.000
		sec	106	74.53	14.15	10.38	0.94	0	4.62	0.000

Note: N = Number of students surveyed; His-Emb = Histology and Embryology; Pat = Pathology; first = first-test questionnaire; Sec = second-test questionnaire. Frequency distribution, mean score, and significance of students' perceptions are reported; first test questionnaire was carried before blended learning and second test questionnaire was carried after blended learning using the non-parametric Wilcoxon signed-rank test. Likert scale item measurements: 1 = strongly disagree (SD), 2 = disagree (D), 3 = neutral (N), 4 = agree (A), 5 = strongly agree (SA). Data are expressed as a percentage of the respondents to both questionnaires of Histology and Embryology and Pathology. *Statistically significant, $p < 0.05$

learning mode as the ideal mode. while 49.06% of students studying Pathology preferred the current blended learning mode (Fig. 3B), and 30.08% preferred traditional offline learning. This suggests that freshmen students (studying Histology and Embryology) are more receptive to the current teaching method, while some of the sophomore students (studying Pathology) were more inclined to prefer the offline teaching mode. It is believed this is because Pathology is a bridging discipline with 50 theory hours and 40 experimental hours in the syllabus, and its proportion of experimental hours is relatively high; consequently, offline study, encompassing slice observation, is also very important. Since students will deal with real patients and solve real problems related to diseases in the future, requiring students to observe slices under microscopes and view real human or animal specimens enables them directly engage in grasping the characters of the specimens, such as the size, color, texture, and so on, so helping them to master related courses such as Pathology is crucial. The questionnaire of subjective views about the integrated ability of blended learning in the intervention group (Table 2) showed that more than 87.73 – 98.86% of the students believed that the current blended learning was superior to totally offline or online teaching modes, with fewer instances of students becoming drowsy or engaging in other distractions.

All students in the intervention group successfully completed online video tasks and chapter tests on time. The course content of various systematic sections (such as cardiovascular, respiratory, digestive, and urology systems) were taught in flipped classroom approach based on some cases. In comparison with the

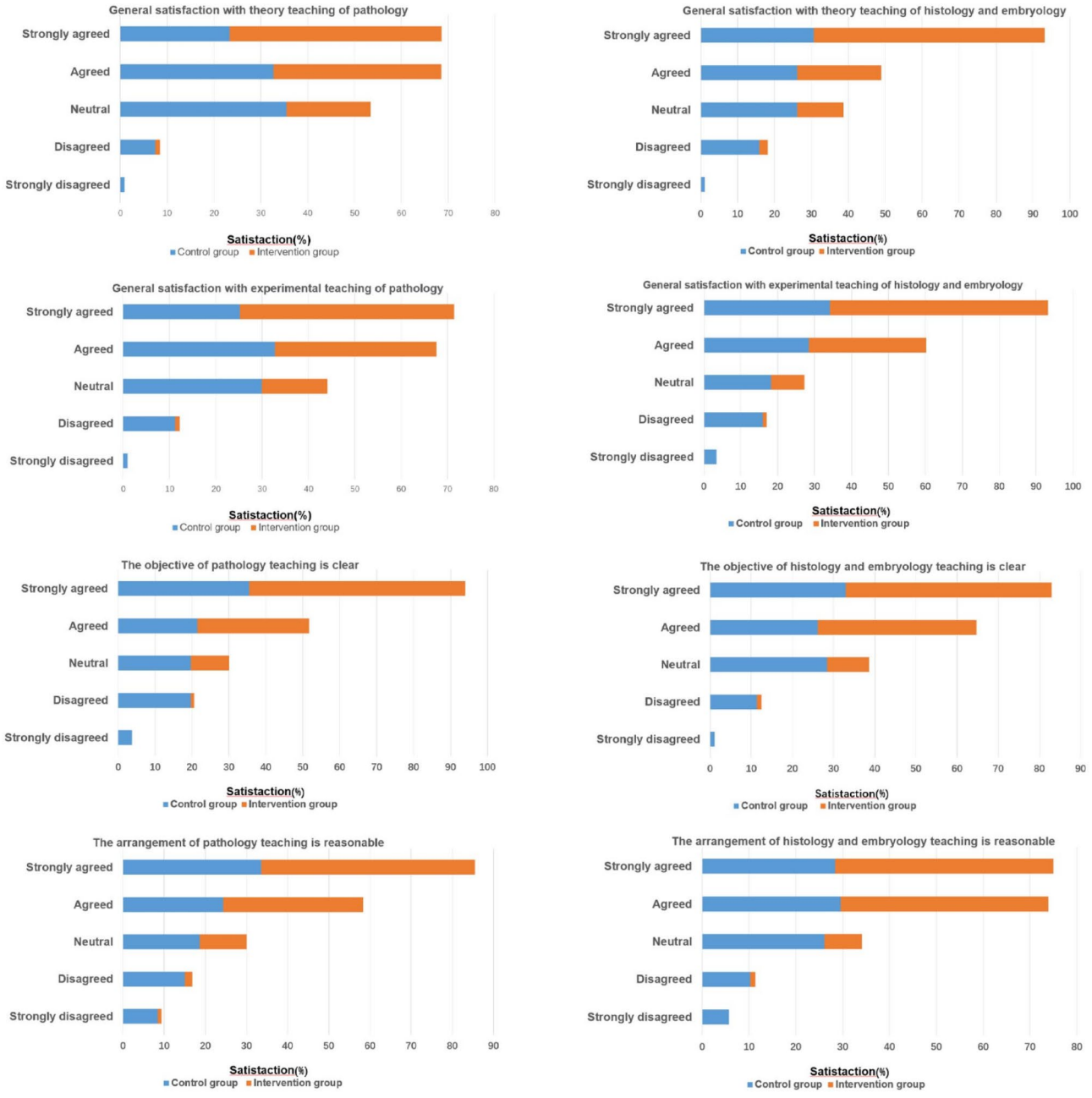

Fig. 2 Students's satisfaction with the teaching of Histology and Embryology or Pathology

first- (Supplementary Material S6) and second- test questionnaires (Supplementary Material S7) in Table 1 illustrates that the results of the second questionnaire were notably superior to those of the first ($P < 0.05$) when considering students' attitudes toward the contents of the flipped theory course, the integration of "Histology and Embryology" and "Pathology", mind mapping, subjective topics, the integrated lectures, and so on. This indicates that, after experiencing blended learning, students gained a deeper comprehension of the blended learning mode and could apply theoretical knowledge more freely. Concerning the writing of subjective topics, students in the intervention group displayed the ability to articulate their perspectives in various dimensions and forms, including related medical, scientific, psychological, and social dimensions, as well as in the forms of the research papers, essays, poems, cartoons (Supplementary Material S8), songs, and animations (Supplementary Material S9). In contrast, those in the control group were more inclined to express opinions through a singular medium (popular science papers). Mind-mapping productions made by the intervention group were both

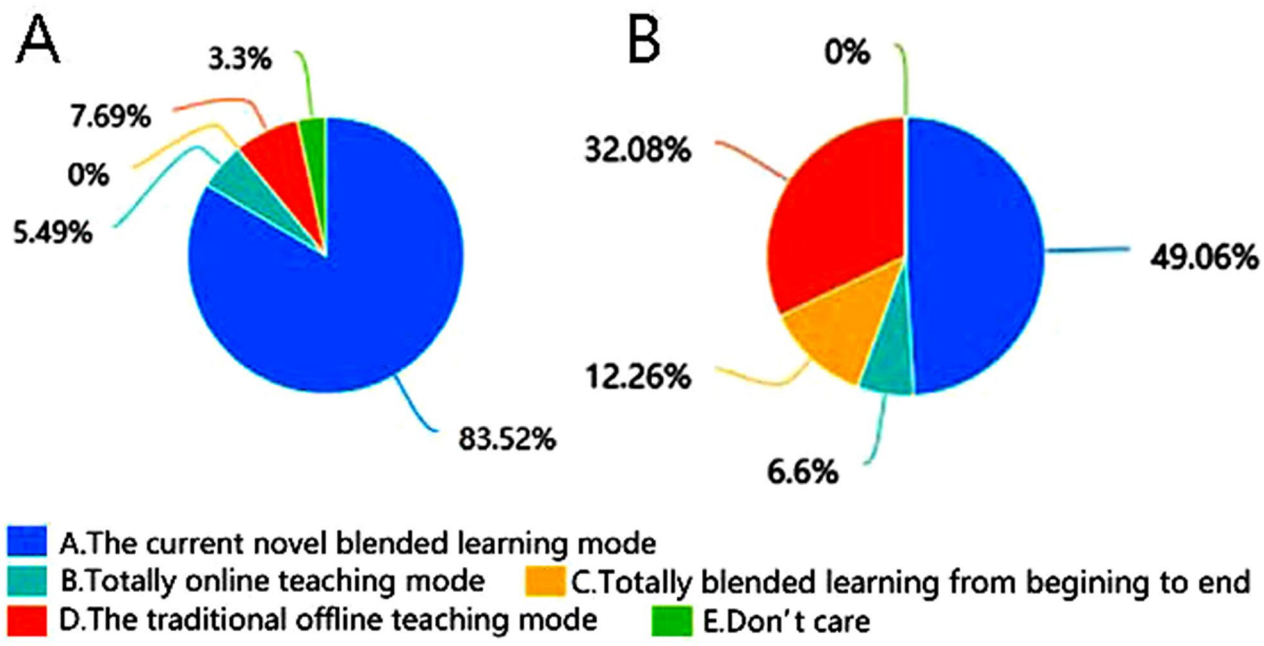

Fig. 3 Proportion of students tending to choose which mode of teaching was best for the future in the intervention group in 2021. (**A**) Students studying Histology and Embryology. (**B**) Students studying Pathology

software-generated (Supplementary Material S10) and hand-written (Supplementary Material S11), whereas the control group predominantly developed hand-written ones. Moreover, the contents of the mind mappings in the intervention group were generally more comprehensive than those in the control group. This demonstrates that the diverse teaching methods employed in the blended learning stimulated the critical thinking among students, broadening their analytical approaches to problem-solving and, consequently, enhancing their multidimensional problem-solving skills.

Figure 4 displays the final written theoretical scores of both the intervention and control groups at the end of the semester. The difference in students who earned 90–100 points between the intervention and the control groups was statistically significant ($P = 0.000$) in a manner favoring students in the intervention group, suggesting that blended learning effectively improves the final written theoretical scores of students with self-directed learning capabilities (Fig. 4). Additionally, the difference in students who scored the 60–70 points between the intervention and control groups was also statistically significant ($P = 0.002$), with the intervention group having significantly fewer students scoring 60–70 points compared to the control group. This suggests that traditional instructive teaching was more advantageous for students with limited self-directed learning abilities. As indicated in Table 3, the final written theoretical scores for Pathology were 74.77 ± 13.25 points (control group) and 83.0 ± 11.85 points (intervention group), respectively, with a statistically significant differences ($P = 0.000$). This suggests that the intervention group exhibited an improved teaching effect, especially for students with a strong inclination to learn and robust self-directed abilities. Blended learning offers more advantages than traditional teaching in this context.

Improved experimental observation ability

Throughout the semester, students in the intervention group participated in a total of 15 flipped experiment classes based on the presented cases, and the final score for pathological experiments (reading slices examination) in the intervention group was 86.88 ± 9.69 points, surpassing that (81.08 ± 13.01 points) of the control group (Table 3) ($P = 0.000$). This indicates that the flipped classroom learning approach during the experimental class effectively enhanced students' observational, linguistic, and explanatory skills. As seen in Fig. 2, the survey on overall satisfaction with the Pathology experimental lectures revealed that the proportions of students in the intervention group who strongly agreed and agreed (50.00% and 34.91%, respectively) were significantly greater than those in the control group (25.23% and 32.71%, respectively; $P = 0.000$). The survey on overall satisfaction with the Histology and Embryology experimental lectures also revealed that the proportions of students in the intervention group who strongly agreed and agreed (57.95% and 31.82%, respectively) were significantly higher than those in the control group (34.09% and 28.41%, respectively; $P = 0.000$).

Table 2 Responses of students' subjective views in the questionnaires about the abilities' enhancement of current blended learning when compared with totally online/offline teaching in intervention group

Survey contents of blended learning model	Course	Teaching models being compared	*N*	Current blended learning is much more helpful compared to totally online/offline teaching. *n* (%)	Current blended learning is helpful, compared to totally online/offline teaching. *n* (%)	Current blended learning is comparable compared to totally online/offline teaching. *n* (%)	Current blended learning is not as helpful as totally online/offline teaching. *n* (%)
In improving learning efficiency, quality and solving difficult problems	His-Emb	Totally online	88	59(67.05)	27(30.68)	2(2.27)	0
		Totally offline	88	54(61.36)	31(35.23)	3(3.41)	0
	Pat	Totally online	106	76(71.7)	24(22.64)	5(4.72)	1(0.94)
		Totally offline	106	60(56.6)	33(31.13)	13(12.26)	0
In mobilizing students' learning enthusiasm, consciousness and initiative	His-Emb	Totally online	88	53(60.23)	30(34.09)	5(5.68)	0
		Totally offline	88	52(59.09)	30(34.09)	6(6.82)	0
	Pat	Totally online	106	69(65.09)	29(27.36)	8(7.55)	0
		Totally offline	106	65(61.32)	29(27.36)	12(11.32)	0
In helping the knowledge summary, integration, application, systematic understanding and memory	His-Emb	Totally online	88	54(61.36)	32(36.36)	2(2.27)	0
		Totally offline	88	52(59.09)	33(37.50)	3(3.41)	0
	Pat	Totally online	106	70(66.04)	33(31.13)	3(2.83)	0
		Totally offline	106	64(60.38)	31(29.25)	11(10.38)	0
In promoting teamwork, language and communication skills, problem solving	His-Emb	Totally online	88	55(62.50)	32(36.36)	1(1.14)	0
		Totally offline	88	52(59.09)	34(38.64)	2(2.27)	0
	Pat	Totally online	106	76(71.7)	26(24.53)	3(2.83)	1(0.94)
		Totally offline	106	68(64.15)	29(27.36)	8(7.55)	1(0.94)

Note: N = Number of students surveyed; His-Emb = Histology and Embryology; Pat = Pathology

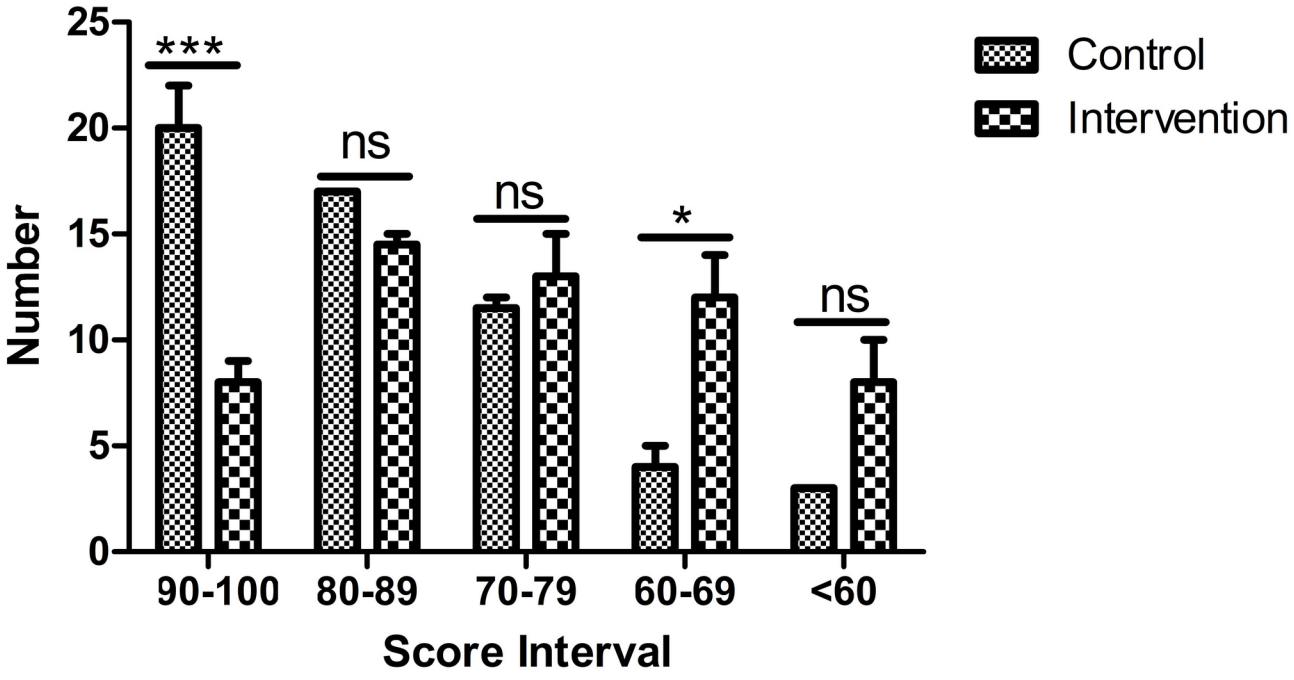

Fig. 4 Different score intervals for the intervention and control groups in the final theory examination of Pathology. Notes: ***: $P<0.001$, **: $P<0.01$, *: $P<0.05$; ns: no statistically significant difference

Table 3 Comparison of scores in theory (final written examination) and experiment (reading slices examination) between intervention group and control group in pathology

Course	Group	*N*	Mean	SD	T	df	Significance level
Pathological theoretical scores	Control	111	74.77	13.25	-4.87	220	0.000***
	Intervention	111	83.00	11.85			
Pathological experimental scores	Control	111	81.08	13.01	3.77	220	0.000***
	Intervention	111	86.88	9.69			

Note: *Statistically significant, $P<0.05$, *** Statistically magnificent significant, $P<0.001$

Abbreviation: N = Number of students; SD = standard deviation; *T* = t test

In the control group, students were exposed to traditional teaching, resulting in passive familiarity with slice observation. Notably, they may have found it difficult to engage in self-directed learning to seek related organizational structures' knowledges, because being passively fed with knowledge has become a common routine. In contrast, in the intervention group, students engaged with a substantial number of online videos and digital slices before class. Most of the questions in class were initiated and addressed by students, who could more actively explore issues in the process of self-directed learning. As shown in Table 1, when asked about whether they were willing to participate in the flipped experiment class, more students in the second questionnaire of the intervention group expressed acceptance (41.18% strongly agreed and 25.88% agreed in the first - test questionnaire for Histology and Embryology compared to 61.36% who strongly agreed and 28.41% who agreed in the second - test questionnaire, respectively; $P=0.000$). Similar trends were observed for Pathology, with 27.36% strongly agreeing and 31.13% agreeing in the first - test questionnaire and 50.94% strongly agreeing and 26.42% agreeing in the second questionnaire ($P=0.000$). However, the control group exhibited little difference between the first- and second - test questionnaires ($P>0.05$). This is attributed to the intervention group having gone through blended learning and truly recognizing its advantages, resulting in greater satisfaction in the second questionnaire. Conversely, the control group did not experience blended learning, making it challenging for them to perceive its benefits (or perhaps they held reservations), leading to no significant difference between the results of the first- and second - test questionnaires.

Discipline competition promotes learning

From Table 1, it is evident that most students expressed a willingness to partake in the competitions. Almost all the students in the intervention group and the control group participated in the activity. However, the students in the intervention group seemed to be more proactive and

active, so the number of winners was also relatively larger. In 2021, two first prizes, three second prizes, and five third prizes were awarded in the university-level painting competition. In addition, excellent drawing works from students (Fig. 5) in the intervention group were selected to participate in the National painting competition, yielding one third prize (Fig. 6A) and one first prize award (Fig. 6B). Meanwhile, the control group only received one third prize in the national painting competition. In 2022, the intervention group also clinched a second prize in the national painting competition (Fig. 6C) and one third prize in the national popular science literature's writing competition (Fig. 6D, Supplementary Material S12). While the control group only garnered one second prize in the university painting competition. Furthermore, we found that the award-winning students all ranked in the top 10% of their class. This underscores that participating in discipline competitions effectively increases students' interest in learning. Moreover, the awards themselves serve as commendations, further motivating them to engage with their studies.

Students' scientific research and practical ability were improved

In 2021, a greater number of students expressed a willingness to participate in scientific interest group (86 were enrolled from the intervention group, while 49 were from the control group). Students from the intervention group demonstrated relatively greater excellence during the scientific research training process, with numerous students participating in national, provincial, and university-level college student innovation and entrepreneurship competitions, as well as basic medical innovation research and experimental design forums, earning related awards as a result. Thirty students from the intervention group consistently participate in the scientific interest group. Eventually, nine students secured prizes in the university-level Competitions, provincial-level, and/or national-level (Supplementary Material S13). Since winning awards can stimulate students' interest in participating, Approximately, one-third of the students remained active throughout the process (30 students in the intervention group, 16 in the control group). A total of 71 students

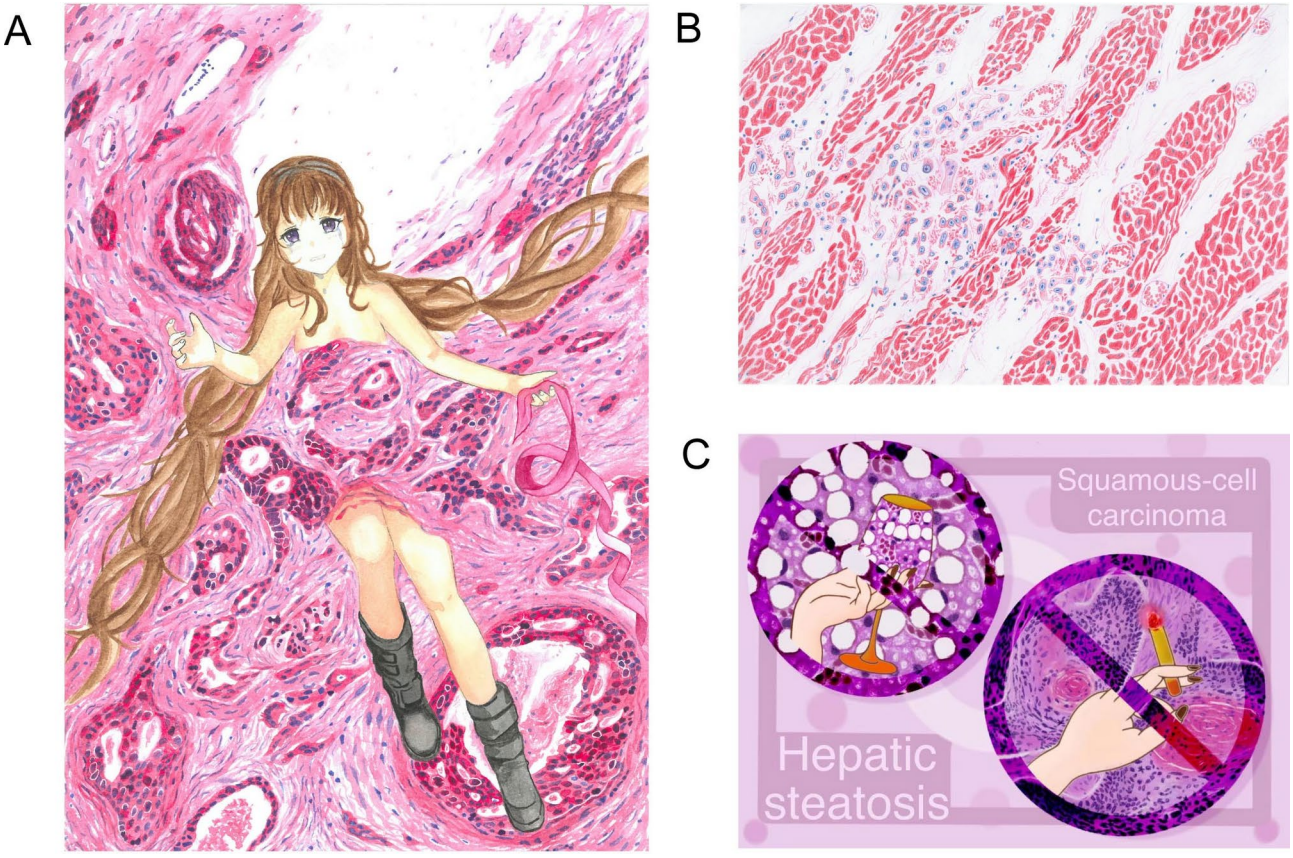

Fig. 5 Excellent drawing works from students in the intervention group. (**A**) The girl is gradually enveloped by cancer cells. She holds a pink ribbon in her left hand, signifying support of the global breast cancer prevention campaign, hoping for "early prevention, early detection, and early treatment". (**B**) Multiple spindle rheumatic bodies can be seen in the interstitium of the myocardium, and various rheumatic cells and cellulose-like necrosis can be seen in the small bodies. (**C**) With the core of "No icon" as the basis, hepatocyte steatosis and lung squamous cell carcinoma are seen. Appearing like a dream bubble in a wine glass, squamous cell carcinoma keratosis beads into the flame of a cigarette end, implying that the joy of tobacco and wine is just a foaming of life

A

B

C

D

Fig. 6 (See legend on next page.)

(See figure on previous page.)

Fig. 6 Excellent works of drawing and popular science literature writing from the intervention group receiving the corresponding national awards. (**A**) The "Breast Cancer" artwork (corresponding to Fig. 5. (**A**)) drawn by students from the intervention group under guidance in 2021 won the third prize of the First National College Students' Medical Morphology Mapping Exhibition. (**B**) The "Rheumatic Myocarditis" artwork (corresponding to Fig. 5. (**B**)) drawn by students from the intervention group under guidance in 2021 won the first prize of the First National College Students' Medical Morphology Mapping Exhibition. (**C**) The "Bad Addiction-the Harm of tobacco and alcohol" (corresponding to Fig. 5. (**C**)) drawn by the students from the intervention group under -guidance in 2022 won the second prize of the Second National College Students' Medical Morphology Mapping Exhibition. (**D**) The "Excellent popular science article about breast cancer" essay written by students from the intervention group under guidance in 2022 (corresponding to Supplemental Material S12) won the third prize of the Second College Students' Medical Morphology Science Essay Competition

(82.56%) in the intervention group persisted until the end of the experiment, while only 35 students (71.43%) in the control group persisted until the end of the scientific interest group.

Forensic pathology is the extension and application of general pathology (21 were enrolled from the intervention group, while 8 were from the control group); after training, students are expected to rethink the importance of related morphological knowledge and learn to integrate the knowledge of various disciplines to solve practical problems. Most participants felt the significance of participating in this activity and persisted active until the end (20 in the intervention group and 7 in the control group).

Discussion

The "Histology and Embryology" and "Pathology" courses play crucial roles in the undergraduate medical curriculum [18]. This study places emphasis on the reverse design and construction of a student-centered curriculum system [19] based on OBE concepts. The objective was to train proficient medical students in scientific thinking, improve their adaptability to the post-epidemic era, enhance their ability to meet clinical needs, and encourage possession of independent analytical and problem-solving skills [20]. To achieve this, the teaching team implemented a novel outcome-based blended learning model aiming at cultivating students' overall qualities, such as the abilities to acquire and apply knowledge, communicate and ask questions, write and draw, conduct scientific research, and so on. According to our findings, this approach serves as an effective teaching modality during the crisis of a pandemic outbreak and was demonstrated to enhance various students' educational experiences, such as their thinking styles, problem-solving capacities, self-discipline, and independent learning skills [21, 22]. Teachers were transformed from disseminators of knowledge into leaders and designers of problems [23], which facilitates teacher-student interaction and fosters a supportive and efficient learning environment [24]. Consequently, the resulting collaborative, friend-tutoring, and participatory approach was better poised to achieve higher-order, innovative, and challenging learning objectives [25].

Online learning serves as a preparatory phase for face-to-face teaching, boasting numerous advantages including rich content, convenience, and flexibility [26, 27]. Subsequently, both horizontal and vertical knowledge integration are reinforced through offline learning. This arrangement encourages students to adopt a more active role in comprehensive and systematic curriculum learning [15]. The flipped classroom also holds significant appeal and feasibility [28]; it fosters deeper engagement, primarily involving team-based activities, and is able to host flexible and varied activities such as presentations, Q&A sessions, discussions, role-plays, argumentative exchanges, and so on [29–31]. This collaborative approach can cultivate students' team spirit, reduce medical errors, and achieve an effect where the whole is greater than the effect, i.e., the sum of $1 + 1 > 2$ [32].

Freshmen and sophomores have limited opportunities to handle clinical cases. As aspiring doctors, they are typically brimming with curiosity, eager to apply newly acquired morphological knowledge to comprehend and elucidate the clinical presentations of patients. We adopted the case-based teaching in select chapters, compelling students to achieve a state of "early clinical, multi-clinical, and repetitive clinical" learning [16]. This inspires them to grasp robust knowledge and cultivate multidimensional thinking [33]. However, the selection and creation of cases require comprehensive and careful consideration: cases should align closely with the syllabus, show novelty, and be carried out according to the good clinical practices. Case teaching represents an in-depth exploration, akin to reading a book and letting it become "thicker". Meanwhile, the process of a mind-mapping creation corresponds to reading a book and let it become "thinner", which can also aide students in distilling key knowledge, enhancing their memory and comprehension of the chapter and course. The amalgamation of these approaches not only broadens students' perspectives but also aids in constructing a sturdy knowledge framework, fostering a deeper comprehension of different diseases.

Digital virtual slices alleviate issues of fading and damage, providing ease in organization, archiving, classification, and viewing [34]. Some research indicates that learning from virtual slices compared to learning from traditional slices engenders a student's greater interest than from traditional slices [35–37]. However, given that clinical pathology work is mainly based upon real slice observation, our emphasis remains on offline glass slices'

observation, with virtual slices serving as only a supplementary tool. This dual teaching approach, integrating real and virtual elements, plus the case-based practical application of a flipped classroom, imparts more solid knowledge acquisition and finally resulted in an elevated standard of experimental teaching.

Encouraging participation in the painting competition and slice recognition contest aided students in their familiarity with histological constructions and pathological changes in each specimen. This not only boosted their interest in painting but also helping them to understand the diverse morphological changes of the disease simultaneously and discover the beauty of the microscopic world, thus making seemingly tedious knowledge become intriguing. Both the appraisement of popular science literature writing and subjective topic completion are based on originality, meaningful contents and rich forms. The activities of various types organized at different levels as mentioned above, can instill a sense of life education, emphasizing the combination of science and beauty, which also promotes the further perfection of personality. Along these lines, we also diligently nurtured members of the scientific research interest group, encouraging them to love scientific research and persistent self-improvement, which will help them to cultivate a habit for scientific inquiry and ultimately develop valuable assets for their future further study. Throughout the entire process of these activities, the number of participants and winners in the intervention group was relatively larger than that in the control group. Moreover, they maintained an active state and persisted until the end relatively more often than those in the control group. This indicates that systematic training for the intervention group seems more likely to stimulate their subjective initiative.

Furthermore, by incorporating clinical knowledge and teaching and attending related integrated lectures, students are better equipped to assimilate into clinical settings, gaining early exposure to clinical applications. This approach enables students to have a more comprehensive understanding of diseases from foundational principles to clinical manifestations, ultimately, helping teachers to shape a cadre of high-caliber medical professionals endowed with independent thinking and innovative prowess.

The intervention group only adopted the blended learning within the systematic course sections this semester. This decision was made by taking into account several factors. First, the academic load for students this semester was substantial; all-encompassing blended learning might have overwhelmed those with weaker self-regulation skills. Second, for those students whose foundational knowledge was not yet solid, some concepts might be challenging to grasp through independent study alone. Figure 3 illustrates that most students endorse the current partially offline and partially blended learning pattern. The results of the questionnaire (Table 2) echo this sentiment, indicating that students in the intervention group perceive the novel blended learning mode as superior to entirely online or entirely offline modes.

Combining diverse educational methods and tools yields more favorable outcomes than using them in isolation [38]. Continuous reflection and innovative, creative strategies are required in the teaching and learning process [39–41]. Consequently, our approach was student-centered, case-based, and outcomes-driven [42, 43] embracing a flexible, novel blended learning model and following a P-C-P-E-S-E teaching sequence. Through practical application, it was observed that the overall teaching effectiveness for the intervention group surpassed that of the control group, a finding substantiated by examination and questionnaire data. This is also consistent with prior studies that have found blended learning to be superior to traditional teaching methods [44–46].

Limitations of the study

The study, conducted in 2021 among clinical medicine students, faced limitations due to limited class hours, impeding students' presentation opportunities. Some struggled with the rapid course pace and diverse teaching methods, especially those with weaker foundations. Addressing these, our team allocated more time to offline teaching when propagating the intervention group's teaching mode to 2022 and 2023. In 2022, questionnaires revealed that 72.31% (Pathology) and 86.36% (Histology and Embryology) of students preferred the novel blended learning mode (Figure A and Figure B, Supplementary Material S14), offering more self-demonstration chances, case analysis, and knowledge expansion. However, self-directed online learning lacked sufficient supervision and evaluation. Future plans include leveraging questionnaire and platform data for direct student communication, enhancing feedback acquisition, and improving teaching design. Additionally, while teaching videos were uploaded to the "Xuexi Tong" platform, they were not in accessible sections, hindering reading data collection. Our teaching model's promotion at Xiangya Medical College received positive feedback, with 89.04% of Pathology students favoring it (Figure C, Supplementary Material S14). Despite these successes, one teaching method doesn't fit all; our research provides references but requires customization. As "Xuexi Tong" introduces AI features in 2024, we aim to leverage them to further enhance educational outcomes.

Conclusions

In summary, the post-COVID-19 era has brought both challenges and opportunities for higher education. Our teaching mode can effectively function new outbreaks or the re-emergence of various epidemics. Undertaking teaching reform and enhancing educational efficacy are imperative for medical education, and teachers serve as the vanguards and conductors of this transformation. As the proverb goes, "Only famous teachers can produce excellent students". Hence, educators forming a teaching team may not only bolster their own learning but also optimize the teaching scheme continually. Of particular importance, they should refine their teaching mode and methods based on students' feedback. While the path to teaching reform is demanding and fraught with challenges, witnessing the progress and score improvements of students brings us great satisfaction and encouragement. Our reform, based on OBE concepts, centered on students, prioritizing their self-directed learning capabilities; emphasizing formative evaluation through the learning process; and promoting active, in-depth, and applied learning. Here, classroom flipping drove learning, experiments helped learning, subjective topics enhanced learning, drawing urged learning, mind-mapping summarized learning, integrated lectures expanded learning, case analysis deepened learning, and scientific research fed learning. This novel blended learning mode of medical morphology, combining normal histological structures with abnormal pathologic changes, reinforcing communication between teachers and students, and implementing various forms of blended learning reforms, can improve students' self-directed learning and comprehensive abilities. Such can lay a solid foundation for students' future clinical learning, and is beneficial for during the post-epidemic era or even in future variable environments. Such can also offer promotional instructive model value to Shandong First Medical University and other medical institutions of the same level.

Abbreviations

OBE	Outcome-based education
SPOC	Small private online courses
COVID-19	Coronavirus disease 2019 epidemic

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12909-025-07280-x.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

Supplementary Material 6

Supplementary Material 7

Supplementary Material 8

Supplementary Material 9

Supplementary Material 10

Supplementary Material 11

Supplementary Material 12

Supplementary Material 13

Supplementary Material 14

Supplementary Material 15

Acknowledgements

The study was carried out thanks to the participation of 405 students from Shandong First Medical University who majoring in clinical medicine who were taking classes on Pathology (Class 2019) or Histology and Embryology (Class 2020).

Author contributions

Qin-lai Liu, Li Ge and Na Yuan contributed to the study conception and design, the analysis and interpretation of data, and the drafting of the paper. Yong-an Wang, Zhao-peng Wang, Chen Fang, Wen-ping Sun, Bai-hua Luo, Lei-ying Yang, Xin Liu and Ya-ling Liu contributed to the analysis and interpretation of data, the drafting and revising of the paper.

Funding

This work was supported by [Shandong Province higher education curriculum ideological and political teaching reform research project] under Grant [SZ2021017]; [Shandong First Medical University education and teaching reform research topic] under Grant [2021XY103], [XM2022050] and [JXGGYJ-22232551]; [Youth Science Foundation of Shandong First Medical University] under Grant [202201-011]; [National Natural Science Foundation of China] under Grant [81401561]; and [Youth Science Foundation of Shandong First Medical University] under Grant [202201-011]; [The Major Project for Teaching Reform Research in Shandong Province] under Grant [T2020001].

Data availability

No datasets were generated or analysed during the current study.

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 informed consent form.

Consent for publication

All subjects have provided consents for participation and publication (Supplementary Material 15).

Competing interests

The authors declare no competing interests.

Author details

[1]School of Clinical and Basic Medical Sciences, Shandong First Medical University & Shandong Academy of Medical Sciences, Qingdao Road 6699, Jinan, Shandong Province 250117, China
[2]Shandong Department of Gastroenterology, The Second Affiliated Hospital of Shandong First Medical University, Shandong First Medical University & Shandong Academy of Medical Sciences, Taian, Shandong 271000, China
[3]School of Laboratory Animal & Shandong Laboratory Animal Center, Shandong First Medical University & Shandong Academy of Medical Sciences, Qingdao Road 6699, Jinan, Shandong 250117, China

[4]Department of Pathology, Xiangya Hospital, Central South University, Xiangya Road 87, Changsha, Hunan 410013, China

Received: 23 August 2024 / Accepted: 5 May 2025
Published online: 17 May 2025

References

1. Jiang Z, Wu H, Cheng H, Wang W, Xie A, Fitzgerald SR. Twelve tips for teaching medical students online under COVID-19. Med Educ Online. 2021;26(1):1854066. PMID: 33280546. https://doi.org/10.1080/10872981.2020.1854066
2. Longhurst GJ, Stone DM, Dulohery K, Scully D, Campbell T, Smith CF, Strength. Weakness, opportunity, threat (SWOT) analysis of the adaptations to anatomical education in the united Kingdom and Republic of Ireland in response to the Covid-19 pandemic. Anat Sci Educ. 2020;13(3):301–11. https://doi.org/10.1002/ase.1967. PMID: 32306550.
3. Zhang XF. COVID-19 prevention and control multiple influences on Chinese higher education. Beijing Educ. 2020;(4):29–31.
4. Pan D. Application of SPOC in online and offline blended teaching mode in universities in the post-pandemic Era. Proceedings of the 2nd international conference on education: Current issues and digital technologies (ICECIDT 2022)2023. pp. 582– 90.
5. Xinhua News Agency. 2019. China issues plans to modernize education. The state council, The People's Republic of China. https://www.gov.cn/zhengce/2019-02/23/content_5367988.htm [accessed 3 August 2024].
6. Shang F, Liu CY. Blended learning in medical physiology improves nursing students' study efficiency. Adv Physiol Educ. 2018;42(4):711–17. https://doi.org/10.1152/advan.00021.2018. PMID: 30431319.
7. Han JH. Research and practice of online and offline integrated teaching in universities during epidemic prevention and control.the. Sci Educ Article Cultures. 2022;1456–9. https://doi.org/10.16871/j.cnki.kjwh.2022.14.017.
8. Liu Q, Sun W, Du C, Yang L, Yuan N, Cui H, et al. Medical morphology training using the Xuexi Tong platform during the COVID-19 pandemic: development and validation of a Web-Based teaching approach. JMIR Med Inf. 2021;9(3):e24497. https://doi.org/10.2196/24497. PMID: 33566792.
9. Spady WG. Outcome-based instructional management: A sociological perspective. Australian J Educ. 2017;26(2):123–43. https://doi.org/10.1177/000494418202600203.
10. Liu Q, Peng W, Zhang F, Hu R, Li Y, Yan W. The effectiveness of blended learning in health professions: systematic review and Meta-Analysis. J Med Internet Res. 2016;18(1). https://doi.org/10.2196/jmir.4807.
11. Lew EK, Nordquist EK. Asynchronous learning: student utilization out of sync with their preference. Med Educ Online. 2016;21:30587. https://doi.org/10.3402/meo.v21.30587. PMID: 27280385.
12. Hyll M, Schvarcz R, Manninen K. Exploring how medical students learn with the help of a digital presentation: a qualitative study. BMC Med Educ. 2019;19(1). https://doi.org/10.1186/s12909-019-1569-z.
13. Kim K-J, Bonk CJ, Oh E. The present and future state of blended learning in workplace learning settings in the united States. Perform Improv. 2008;47(8):5–16. https://doi.org/10.1002/pfi.20018.
14. Vallee A, Blacher J, Cariou A, Sorbets E. Blended learning compared to traditional learning in medical education: systematic review and Meta-Analysis. J Med Internet Res. 2020;22(8):e16504. https://doi.org/10.2196/16504. PMID: 32773378.
15. Martínez-Muñoz, and Estrella Pulido. Using a SPOC to flip the classroom. 2015 IEEE global engineering education conference (EDUCON): Page 431– 36. https://doi.org/10.1109/EDUCON.2015.7096007
16. Huang C, Wu N, Zhu D, Zhang D, Luo TY, Xu P. Countermeasures of early clinical, multi-clinical and repeated clinical for medical undergraduates. Chin J Med Educ Res. 2022;21(6):705–8.
17. DigiHuman. Shandong first medical university STEM morphology system. https://sdfmu.humanyun.com. [accessed 3 August 2024].
18. Lee BC, Hsieh ST, Chang YL, Tseng FY, Lin YJ, Chen YL, et al. A Web-Based virtual microscopy platform for improving academic performance in histology and pathology laboratory courses: A pilot study. Anat Sci Educ. 2020;13(6):743–58. https://doi.org/10.1002/ase.1940. PMID: 31883209.
19. Liang J, Ning X, OBE Concept for New Training Mode of Electronic Information Science and Technology Professionals under Big Data Analysis. Comput Intell Neurosci. 2022;2022:1–10. https://doi.org/10.1155/2022/8075708.
20. Hu XM, Li ZX, Deng J, Han Y, Lu S, Zhang Q, et al. Integration of theory and practice in medical morphology curriculum in postgraduate training: A flipped classroom and Case-based learning exercise. Curr Med Sci. 2023;43(4):741–48. https://doi.org/10.1007/s11596-023-2759-9. PMID: 37455278.
21. Green RA, Whitburn LY. Impact of introduction of blended learning in gross anatomy on student outcomes. Anat Sci Educ. 2016;9(5):422–30. https://doi.org/10.1002/ase.1602. PMID: 26929149.
22. Chen J, Zhou J, Wang Y, Qi G, Xia C, Mo G, et al. Blended learning in basic medical laboratory courses improves medical students' abilities in self-learning, understanding, and problem solving. Adv Physiol Educ. 2020;44(1):9–14. https://doi.org/10.1152/advan.00076.2019. PMID: 31821032.
23. Carbonaro M, King S, Taylor E, Satzinger F, Snart F, Drummond J. Integration of e-learning technologies in an interprofessional health science course. Med Teach. 2008;30(1):25–33. https://doi.org/10.1080/01421590701753450. PMID: 18278648.
24. Falck A, French H, Dadiz R, Gray MM, Mendres-Smith A, Nolan B, et al. Best practices and educator strategies for facilitating a flipped classroom in graduate medical education. Am J Perinatol. 2023. https://doi.org/10.1055/s-0043-1772227.
25. Wu Y. Golden course construction of China. Chin Univ Teach. 2018;124–9. https://doi.org/10.3969/j.issn.1005-0450.2018.12.002.
26. Garrison DR, Kanuka H. Blended learning: Uncovering its transformative potential in higher education. Internet High Educ. 2004;7(2):95–105. https://doi.org/10.1016/j.iheduc.2004.02.001.
27. Joynes V, Fuller R. Legitimisation, personalisation and maturation: using the experiences of a compulsory mobile curriculum to reconceptualise mobile learning. Med Teach. 2016;38(6):621–27. https://doi.org/10.3109/0142159X.2015.1075651. PMID: 26384108.
28. Sierra-Fernandez CR, Alejandra HD, Trevethan-Cravioto SA, Azar-Manzur FJ, Mauricio LM, Garnica-Geronimo LR. Flipped learning as an educational model in a cardiology residency program. BMC Med Educ. 2023;23(1):510. PMID: 37460995. https://doi.org/10.1186/s12909-023-04439-2
29. Al-Samarraie H, Shamsuddin A, Alzahrani AI. A flipped classroom model in higher education: a review of the evidence across disciplines. Education Tech Research Dev. 2019;68(3):1017–51. https://doi.org/10.1007/s11423-019-09718-8.
30. Malhotra AS, Bhagat A. Flipped classroom for undergraduate medical students in India: are we ready for it? Adv Physiol Educ. 2023;47(4):694–98. https://doi.org/10.1152/advan.00200.2022. PMID: 37471219.
31. Jordan C. Using a flipped classroom and Role-Play to introduce nursing students to LGBTQIA + Patient care. Nurs Educ Perspect. 2023;44(5):323–25. https://doi.org/10.1097/01.NEP.0000000000001183. PMID: 37594432.
32. Lerner S, Magrane D, Friedman E. Teaching teamwork in medical education. Mt Sinai J Med. 2009;76(4):318–29. https://doi.org/10.1002/msj.20129. PMID: 19642146.
33. Cai L, Li YL, Hu XY, Li R. Implementation of flipped classroom combined with case-based learning: A promising and effective teaching modality in undergraduate pathology education. Med (Baltim). 2022;101(5):e28782. https://doi.org/10.1097/MD.0000000000028782. PMID: 35119043.
34. Chang JY, Lin TC, Wang LH, Cheng FC, Chiang CP. Comparison of virtual microscopy and real microscopy for learning oral pathology laboratory course among dental students. J Dent Sci. 2021;16(3):840–45. https://doi.org/10.1016/j.jds.2021.03.011. PMID: 34141097.
35. Marchevsky AM, Relan A, Baillie S. Self-instructional virtual pathology laboratories using web-based technology enhance medical school teaching of pathology. Hum Pathol. 2003;34(5):423–29. https://doi.org/10.1016/s0046-8177(03)00089-3. PMID: 12792914.
36. Blake CA, Lavoie HA, Millette CF. Teaching medical histology at the university of South Carolina school of medicine: transition to virtual slides and virtual microscopes. Anat Rec B New Anat. 2003;275(1):196–206. https://doi.org/10.1002/ar.b.10037. PMID: 14628320.
37. Kumar RK, Velan GM, Korell SO, Kandara M, Dee FR, Wakefield D. Virtual microscopy for learning and assessment in pathology. J Pathol. 2004;204(5):613–18. https://doi.org/10.1002/path.1658. PMID: 15470688.
38. Khalaila R. Simulation in nursing education: an evaluation of students' outcomes at their first clinical practice combined with simulations. Nurse Educ Today. 2014;34(2):252–58. https://doi.org/10.1016/j.nedt.2013.08.015. PMID: 24060462.
39. Aredes NDA, Góes FdSNd, Silva MAI, Gonçalves MFC, Fonseca LMM. Digital object in neonatal nursing: impact on student learning. Revista Eletrônica De Enfermagem. 2015;17(4):1–11. https://doi.org/10.5216/ree.v17i4.34856.

40. Ocak MA. Blend or not blend: a study investigating faculty members' perceptions of blended teaching. World J Educ Technol. 2010;2(3):196–210.
41. Jokinen P, Mikkonen I. Teachers' experiences of teaching in a blended learning environment. Nurse Educ Pract. 2013;13(6):524–28. https://doi.org/10.1016/j.nepr.2013.03.014.
42. Harden RM. Outcome-Based education: the future is today. Med Teach. 2007;29(7):625–29. https://doi.org/10.1080/01421590701729930. PMID: 18236247.
43. Yang R, Huang J, Tong XM, Zhang P, Yao YH, Wu LF. An exploration on OBE-based teaching model of medical metabolic biochemistry. Basic Clin Med. 2020;40(3):415–18. https://doi.org/10.16352/j.issn.1001-6325.2020.03.013.
44. Wu J-H, Tennyson RD, Hsia T-L. A study of student satisfaction in a blended e-learning system environment. Comput Educ. 2010;55(1):155–64. https://doi.org/10.1016/j.compedu.2009.12.012.
45. Demirer V, Sahin I. Effect of blended learning environment on transfer of learning: an experimental study. J Comput Assist Learn. 2013;29(6):518–29. https://doi.org/10.1111/jcal.12009.
46. Lozano-Lozano M, Fernandez-Lao C, Cantarero-Villanueva I, Noguerol I, Alvarez-Salvago F, Cruz-Fernandez M, et al. A blended learning system to improve motivation, mood State, and satisfaction in undergraduate students: randomized controlled trial. J Med Internet Res. 2020;22(5):e17101. https://doi.org/10.2196/17101. PMID: 32441655.

Publisher's note