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Implementation and evaluation of online and offline blended teaching model in laboratory course of Clinical Laboratory Hematology

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This study explores the implementation and evaluation of online and offline blended teaching model in the Clinical Laboratory Hematology (CLH) laboratory course at Chengdu Medical College. To this end, 90 students majoring in medical laboratory technology in 2020 were selected as research subjects and randomly divided into experimental and control groups. The experimental group adopted an online and offline blended teaching model, while the control group adopted a traditional one. After-class tests, laboratory examinations, questionnaire surveys, and student interviews were conducted to evaluate the teaching effectiveness. The average scores of both tests and examinations in the experimental group were significantly higher than those in the control group ($p < 0.05$). Furthermore, the results of the feedback questionnaire showed that the satisfaction and self-evaluation of the learning effect of students in the experimental group were significantly better than those in the control group ($p < 0.05$). The blended teaching model has been successful and popular in CLH. This is a useful teaching mode worth applying to laboratory teaching in medical courses.

KEYWORDS

online and offline, blended teaching model, Clinical Laboratory Hematology, laboratory course, medical laboratory

Introduction

During the past 3 years of Corona Virus Disease 2019 in China, the medical laboratory profession has responded magnificently to various challenges (Zhang et al., 2020). Education in medical laboratory is also required to improve the quality of talent training to address these challenges. Clinical Laboratory Hematology (CLH) is one of the core professional courses in medical laboratory and is recognized as practical, intricate, and multidisciplinary (Rizk, 2018). Students in this course are required to develop practical skills, especially in cell morphology recognition.

Clinical Laboratory Hematology is generally divided into theoretical and laboratory courses. In the traditional laboratory classroom, the teacher first gave a short lecture referring to key and difficult aspects of the current laboratory course. Subsequently, the students followed instructions to observe marrow cell morphology with marrow smears through microscopes step-by-step (Bian et al., 2018). However, the majority of the bone marrow smears

and microscopes in use are outdated, primarily due to two main reasons. First, the bone marrow smears utilized in our course's laboratory teaching have deteriorated in quality over time from extensive use and cleaning, which significantly impacts students' experiences when examining slides under the microscope. These slides are mostly provided by clinical technicians from the affiliated hospital's laboratory department. The high demand for teaching slides, coupled with the time-consuming processes of slide preparation and staining, and the busy schedules of clinical technicians, result in a delay in replenishing and replacing the aging teaching materials. Second, the frequent use of microscopes has led to severe wear and tear, further affecting students' slide-reading experiences. The high cost of microscopes and the large quantities required for procurement also mean that it is impractical to replace outdated microscopes in a timely manner. This situation has led to a concerning finding: after completing the course, most students exhibit weak cell morphology recognition skills. This deficiency in basic skills has a domino effect, resulting in weaker practical skills during the clinical practice stage. Moreover, this presents a significant challenge for CLH educators, who must address the issue of outdated teaching materials and equipment to ensure that students develop the necessary skills for their future careers in clinical.

The online and offline blended teaching aims to lead students from a superficial to a deep and full understanding of the courses. It offers a promising way of transforming teaching methods in educational careers and has been reported to positively affect many subjects (Guillén-Gámez et al., 2024; Palacios-Rodríguez et al., 2025; Talan et al., 2024; Goldberg and Crocombe, 2017; McLaughlin et al., 2015). With the spread of wireless fidelity on Chinese campuses and the increasing availability of online teaching systems and platforms, educators at Chinese universities are instigating a wave of blended teaching reforms (Shang and Liu, 2018).

The flipped classroom is a pedagogical approach where learning activities are rearranged to be effective in providing the educators more face-to-face interactions with students (Fatima et al., 2017; Rotellar and Cain, 2016). This teaching method is constructively based on the student-centered teaching concept, and gives full play to students' subjective initiative, so as to improve the learning outcomes (Cho et al., 2021; Dooley et al., 2018).

To improve students' learning effect of laboratory courses in CLH as well as skills in cell morphology recognition and study motivation, an online and offline teaching model with flipped classroom for our laboratory course has been designed and implemented in the medical laboratory major of our school. Meanwhile, the implementation effect was evaluated by an after-class test, laboratory examination, questionnaire survey, as well as student interviews and compared with the traditional teaching model.

Materials and methods

Participants

This study was conducted at the School of Laboratory Medicine at Chengdu Medical College. Accordingly, 90 undergraduates in the third grade majoring in medical laboratory technology were selected as research subjects. Subsequently, 30 students from Class 1 were divided into an experimental group using online and offline blended teaching model with flipped classroom. The remaining 60 students, Classes 2 and 3, were divided into control group, using a traditional teaching model, respectively. Students from the three classes were evenly assigned to parallel classes based on their college entrance examination scores, including Chinese, Mathematics, English and Science Comprehensive subjects scores. There were no significant differences in age or sex between the two groups ($p > 0.05$, Supplementary material). All students took theory courses in CLH in the same class. All procedures in this study were approved by the Ethics Committee of Chengdu Medical College, and informed consent was obtained from all students (2021NO. 09).

Teaching method

The online and offline blended teaching model

The experimental group used blended online and offline teaching model. A blended teaching model was built using an online cell morphology resource library.[1] The online resource library contains both normal and pathological marrow cell morphology related to textbooks. Students can view the photographs of single marrow cells and the marrow images in an online resource library with a magnifying or contractible view. The correct answers of the cells were clicked to reveal. Thus, the problem of time-worn marrow smears and microscopes was solved online.

Teaching content

According to the teaching objectives, syllabus, and textbook content, important laboratory teaching content of cell morphology was selected using the online and offline blended teaching model with flipped classroom (Table 1).

Teaching implementation

Before laboratory class

In the CLH curriculum system, the students acquired cell morphology knowledge in theory courses and then practiced in the laboratory class to develop cell morphology-recognized skills. For example, the teaching content of the first laboratory class included normal marrow cell morphology, including granulocytes, normoblasts, and megakaryocytes. First, the teacher taught professional knowledge of cell morphology in a theory class. After the theory class, the teacher uploaded the learning goals of the laboratory class to the online teaching platform and required students to look through the cell morphology online to preview before the laboratory class.

In laboratory class

First, knowledge review: the teacher systematically summarized the key and difficult aspects of morphology taught in theory class. Then, an observation assignment was given to the students to finish in class.

1 http://e-lab.cmc.edu.cn/virlab/

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TABLE 1 The difference between the on-line and off-line blended teaching model and traditional teaching model.

Order	Teaching content	Online and offline blended teaching model			Traditional teaching model	
		Teaching period	Flipped classroom	Teaching model	Teaching period	Teaching model
1	Normal marrow cell morphology (granulocytes, normoblasts, and megakaryocytes)	3 classes, last class for flipped classroom (120 min)	Briefly describe the cell morphology of granulocytes, normoblasts, and megakaryocytes	On line students observed marrow cells with an online resource library.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
2	Normal marrow cell morphology (lymphocytes, monocytes and plasmacytes)	3 classes, last class for flipped classroom (120 min)	Briefly describe the cell morphology of lymphocytes, monocytes and plasmacytes	On line students observed marrow cells with an online resource library.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
3	Observation of normal marrow cell morphology with microscopes	3 classes, last class for flipped classroom (120 min)	Briefly describe the diagnostic criteria for a normal bone marrow	Off line students observed marrow cells with marrow smears through microscopes.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
4	Marrow cell morphology in cytochemical stain	3 classes, last class for flipped classroom (120 min)	Briefly describe the clinical significance of the several types of cytochemical stain	On line students observed marrow cells with an online resource library.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
5	Anemia marrow cell morphology	3 classes, last class for flipped classroom (120 min)	Clinical case analysis of megaloblastic anemia	On line students observed marrow cells with an online resource library.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
6	Cytochemical stain experiment and observation of anemia marrow cell morphology with microscopes	3 classes, last class for flipped classroom (120 min)	Clinical case analysis of iron deficiency anemia	Off line students observed marrow cells with marrow smears through microscopes.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
7	CL marrow cell morphology (CML and CLL)	3 classes, last class for flipped classroom (120 min)	Clinical cases case analysis of CML	On line students observed marrow cells with an online resource library.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
8	AL marrow cell morphology (AML and ALL)	3 classes, last class for flipped classroom (120 min)	Clinical case analysis of APL	On line students observed marrow cells with an online resource library.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
9	MM and MDS marrow cell morphology	3 classes, last class for flipped classroom (120 min)	Clinical case analysis of MM	On line students observed marrow cells with an online resource library.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.
10	Observation of leukemia, MM and MDS marrow cell morphology with microscopes	3 classes, last class for flipped classroom (120 min)	Briefly describe the key points in differentiating the above diseases with their bone marrow morphology	Off line students observed marrow cells with marrow smears through microscopes.	3 classes without flipped classroom (120 min)	Off line students observed marrow cells with marrow smears through microscopes.

MgA, megaloblastic anemia; IDA, iron deficiency anemia; CL, chronic leukemia; CML, chronic myelogenous leukemia; CLL, chronic lymphocytic leukemia; AL, aucte leukemia; AML, aucte myelogenous leukemia; ALL, aucte lymphocytic leukemia; APL, acute promyelocytic leukemia; MM, multiple myeloma; MDS, myelodysplastic syndrome.

Second, online observation of cell morphology: the students used an online resource library to observe marrow cells. Offline observation of cell morphology: the students observed marrow cells with marrow smears using a microscope. Either through online or offline observation, students could communicate with the teacher at once if they had any questions about the marrow cell morphology they were observing.

Finally, flipped classroom: during the last 40 min of the class, the teacher set up several questions or a case analyses of the current class's

teaching content. Students then worked in groups to discuss and analyze the questions and case raised by the teacher and used the morphological knowledge they had mastered to answer and solve the problems. Teachers would correct their mistakes and supplement their answers.

After laboratory class

Students were required to review the cell morphology learned in class using an online resource library after class.

The traditional teaching model

The control group used a traditional offline teaching model. The control and experimental groups were taught by the same teacher, and the teaching content and duration were the same. However, students in the control group observed marrow cells with marrow smears through microscopes without an online resource library. Finally, the teacher made a summary speech on the students' performance in the classroom. Additionally, students are also required to preview and review laboratory learning content before and after class using textbooks instead of the online resource library.

Effect evaluation

The after-class test

After each laboratory class, as shown in Table 1, approximately 10 choice questions were selected to test the students' skills in cell morphology recognition. Next, we compared the average test scores of the two groups using the different teaching models.

The laboratory examination

After completing the whole laboratory course, a laboratory examination was conducted to evaluate students' mastery of cell morphology recognition skills. The examination contained 10 choice questions about normal marrow cell morphology and 10 choice questions about pathologic marrow cell morphology. Finally, the average test scores of the two groups were compared.

The questionnaire survey

At the end of the course, a questionnaire was distributed to students in the form of an online electronic questionnaire. Students completed the questionnaires independently and anonymously. The questionnaire was designed based on validated questionnaires from previous studies (Diel et al., 2021; Hameed et al., 2020). The responses were scored using a 5-point Likert scale (ranging from 1 = strongly disagree to 5 = strongly agree) to evaluate the satisfaction and learning effects of the teaching models on students. The reliability of the scale was assessed using Cronbach's alpha (Bian et al., 2018). The Cronbach's alpha for the student satisfaction questionnaire on the current teaching model and the self-assessment questionnaire on learning effectiveness are 0.89 and 0.86, respectively.

Statistical analysis

Data were statistically analyzed using the SPSS software (version 25.0; International Business Machines Corp., Armonk, NY, USA). Both the test and examination scores were analyzed using an independent sample t-test. The Wilcoxon signed-rank test was used to compare questionnaire survey responses between the two groups. The distribution of the questionnaire scores was skewed. $p < 0.05$ is considered statistically significant.

Results

After class test score

As shown in Figure 1, the average test score of the experimental group was significantly higher than that of the control group ($p < 0.01$, Figure 1).

Experimental examination score

Furthermore, the experimental examination score was significantly higher in the experimental group than in the control group ($p < 0.05$, Figure 1).

Students' questionnaire results

We sent 90 copies of the questionnaires to the students, and 90 copies were received, with a recovery rate of 100%.

Table 2 shows the two groups of students' responses to their satisfaction with the current teaching model. We found that the degree of satisfaction in the experimental group was much higher than that in the control group. In addition, to determine how satisfied students were with the frequency of online laboratory classes and the online cell morphology resource library, we designed questions 4 and 5 for the experimental group students only. It was found that 90% of the students in the experimental group were satisfied with the frequency of online classes. Subsequently, 93.33% of the students were satisfied with the online library.

Moreover, the Wilcoxon test showed that higher scores for the three questions were obtained in the experimental group than in the control group ($p < 0.01$) (Figure 2). Compared with the traditional

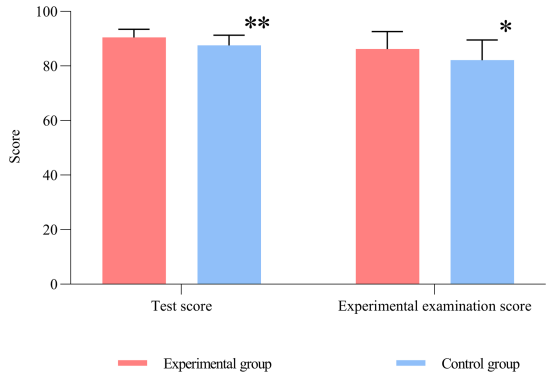

FIGURE 1
Comparison of average scores in after-class tests and laboratory examinations between experimental and control groups. *$p < 0.05$, **$p < 0.01$ vs. Control group.

TABLE 2 Responses from students regarding the satisfaction to current teaching model.

Question number	Question	Experimental group (n = 30)			Control group (n = 60)		
		SA\A (%)	U (%)	D\SD (%)	SA\A (%)	U (%)	D\SD (%)
Q1	You satisfied with the current teaching model.	90.00	10.00	0	55.00	30.00	15.00
Q2	You satisfied with the contents of the current teaching model.	93.33	3.33	3.33	66.67	26.67	6.66
Q3	You satisfied with the organization and preparedness for the current teaching model.	96.67	3.33	0	63.33	25.00	11.67
Q4 For experimental group only	You satisfied with the frequency of online laboratory classes.	90.00	6.67	3.33			
Q5 For experimental group only	You satisfied with the online cell morphology resource library for laboratory course.	93.33	6.67	0			

SA, Strongly agree; A, Agree; U, uncertainty; D, Disagree; SD, Strongly disagree.

teaching model, the degree of satisfaction of students with the blended teaching model was significantly improved ($p < 0.01$), including greater satisfaction with the teaching content ($p < 0.01$) and organization and preparedness for laboratory courses ($p < 0.01$). These results suggest that the novel teaching model was more popular than the traditional one.

The results of the feedback survey administered to students regarding the learning effects of the current teaching model are summarized in Table 3. The Wilcoxon test showed that the blended laboratory courses exhibited more positive scores for each of the five questions relative to the neutral response value ($p < 0.05$) (Table 3 and Figure 3), indicating that students with blended teaching model had better self-evaluations of learning effects than those with the traditional model.

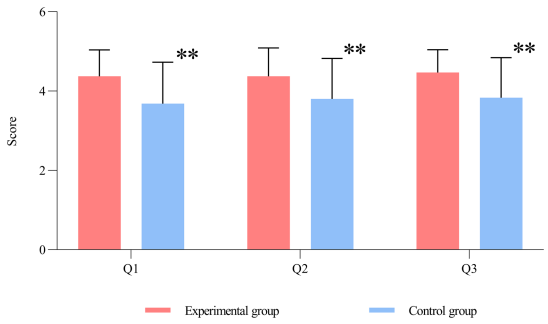

FIGURE 2
Comparison of course satisfaction scores between experimental and control groups. **$p < 0.01$ vs. Control group.

Discussion

It is widely believed that Clinical Laboratory Hematology, with its tedious and intricate content, covers a wide range of disciplines (Qutob, 2022). Furthermore, marrow smears and microscopes used in nearly all laboratory classes were too dated for practical use. As a result, the traditional laboratory course further reduced students' learning enthusiasm and initiative. Thus, students could not understand or master morphology knowledge, and their cell morphology recognition skills were weaker, which was a major challenge for educators.

This study aims to explore how to apply the online and offline blended teaching model in a CLH laboratory course to make difficult and tedious content easier to understand. Thus, students can improve their learning effect and enhance their practical skills in cell morphology recognition. Moreover, the application effect of this teaching model was evaluated through tests and questionnaire surveys, then compared with the traditional teaching model. The multidimensional evaluation indicators revealed that the teaching effect of the novel model was significantly better than that of the traditional teaching model ($p < 0.05$).

It is reported that blended teaching provides better teaching outcomes than either offline or online teaching alone (Liu et al., 2016; Vallée et al., 2020), consistent with our study. The blended teaching model was significantly different from the traditional model in terms of the design before class, in class, and after class (Bajpai et al., 2019; MacNeill et al., 2023). First, a preview section was created before the class. According to the learning goals uploaded by the teachers online in advance, the students were required to scan the morphology content online for a preview. Therefore, students' fear of tedious and difficult morphological knowledge was appropriately reduced.

The second was a class study section. As shown in Table 1, we set up online classes before offline classes, and the content of the online classes was easier than that of the offline ones. In the online class, students were required to observe single cells first and then observe the marrow images after gaining a certain understanding of single-cell

TABLE 3 Responses from students regarding the self-evaluation in learning effect.

Question number	Question	Experimental group (n = 30)			Control group (n = 60)		
		SA\A (%)	U (%)	D\SD (%)	SA\A (%)	U (%)	D\SD (%)
Q1	The current teaching model were better at fulfilling learning objectives	90.00	6.67	3.33	58.33	26.67	15.00
Q2	The current teaching model stimulate your learning interest in Clinical Laboratory Hematology.	86.67	10.00	3.33	51.67	35.00	13.33
Q3	The current teaching model improve the ability of cell morphology recognition.	86.67	6.67	6.67	56.67	25.00	18.33
Q4	The current teaching model enhance you understanding the theory knowledge	90.00	10.00	0	68.33	11.67	20.00
Q5	The current teaching model develop your ability to analyze and solve problems.	90.00	6.67	3.33	55.00	21.67	23.33

SA, Strongly agree; A, Agree; U, uncertainty; D, Disagree; SD, Strongly disagree.

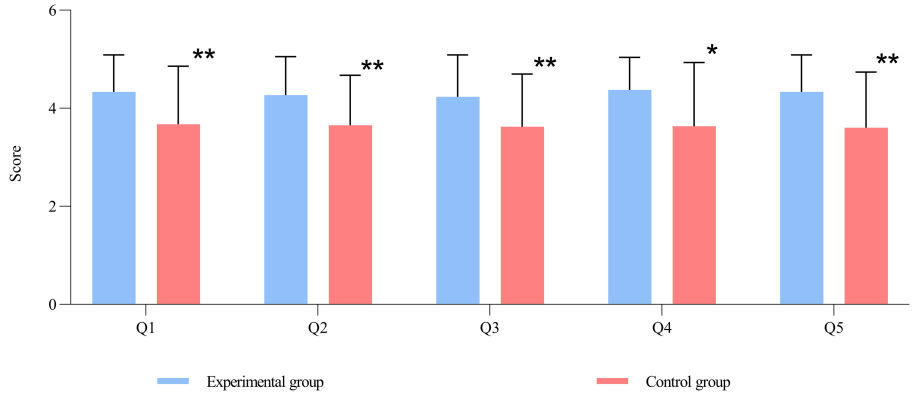

FIGURE 3
Comparison of self-evaluation in learning effect scores between experimental and control groups. *p < 0.05, **p < 0.01 vs. Control group.

morphology. They must recognize the cells by themselves and then click on the cell to view the answers. After completing one or more online laboratory classes, students were arranged to take one offline class to observe marrow smears with microscopes. This arrangement of laboratory courses conformed to students' cognition so that they acquired the knowledge and mastered the skills which were considered tedious and difficult well (Chen et al., 2020; Shang and Liu, 2018). In addition, we conducted a classroom interaction as a flipped classroom in the last period of the class. This can significantly stimulate students' enthusiasm for learning and develop their abilities to analyze and solve problems (Granero Lucchetti et al., 2018; Zhang et al., 2019).

Finally, a review was conducted after the class. Students can access the online resource library anytime via phone or computer. Thus, the fragmentation time can be used to review cell morphology to improve the learning effect (Daniel et al., 2021). In summary, through the novel teaching model, students' learning enthusiasm and initiative were stimulated, the learning effect was improved, and cell morphology-recognition skills were enhanced.

To the best of our knowledge, this study provides the first report of that the online and offline blended teaching model combining with flipped classroom were implemented in laboratory course of CLH. The research results indicate that this novel teaching model has been successful. Why is a blended laboratory course successful? Besides student cooperation, educators' cognition and accumulation in the past, extended preparation time were also important reasons (Chen et al., 2022; Zeng et al., 2021). The pre-class preparation, in-class implementation, and post-class evaluation of the blended teaching model, which educators designed, demonstrated their teaching ability

and experience. Specifically, the school leader drawn up a plan and allocated the tasks. Both doctors in clinical laboratories and professional teachers in schools cooperated to select the morphology content to be taught using a blended teaching model. Scientific and technical corporations manufactured the online resource library. Teachers taught students using the blended teaching model in class and evaluated the teaching effect using multidimensional indicators after class. Finally, the data were analyzed to evaluate the implementation effect of the blended teaching model. All members of the CLH teaching team performed the entire process. Thus, the teachers' teaching ability improved significantly, and the cohesive force of the team was enhanced.

While our research has yielded positive results, there are still certain limitations. We only selected a single batch of students receiving blend or traditional teaching model as our research subjects, which, due to the limitations of sample size and batches, may introduce some bias into the results (Bock et al., 2021). In our next phase of research, we intend to broaden our scope by including multiple batches of students under instruction to increase the sample size, allowing for a more in-depth validation of our research findings. Furthermore, using an online resource library for the review of bone marrow smears has solved the problem of poor student learning experience caused by outdated bone marrow slides and microscopes in real-life teaching. Although we arranged offline laboratory sessions for students to observe bone marrow cells under microscopes, it has also reduced the frequency with which students use microscopes. This could potentially lead to a decrease in students' proficiency in using microscopes. To counteract this drawback, teachers should pay more active attention to each student's use of microscopes during offline microscope slide observation laboratory sessions, providing timely guidance to help students become proficient in using microscopes for the observation of bone marrow smears, thereby consolidating students' microscope operation skills.

Conclusion

The blended teaching model with flipped classroom was successful and welcomed by both students and teachers in CLH course. Thus, education in medical laboratory should not be conservative. Professional education should be innovative to improve student learning effect and enhance practical skills. Then, the training level of laboratory talent can be improved to address the challenge of identifying known and unknown diseases. In future studies, virtual simulation technology will be used in our laboratory course for an online laboratory class on leukemia flow cytometry experiment. We are unremittingly innovating medical laboratory education.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Ethics Committee of Chengdu Medical College. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DL: Writing – original draft, Writing – review & editing, Conceptualization, Methodology, Project administration. FW: Conceptualization, Writing – original draft, Writing – review & editing. XZ: Methodology, Resources, Writing – original draft. KP: Methodology, Resources, Writing – original draft. LZ: Writing – review & editing, Formal analysis, Visualization. HY: Data curation, Formal analysis, Writing – original draft. XL: Data curation, Formal analysis, Writing – original draft. JZ: Writing – original draft, Writing – review & editing, Conceptualization, Project administration.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1497477/full#supplementary-material

References

Bajpai, S., Semwal, M., Bajpai, R., Car, J., and Ho, A. H. Y. (2019). Health professions' digital education: review of learning theories in randomized controlled trials by the digital health education collaboration. *J. Med. Internet Res.* 21:e12912. doi: 10.2196/12912

Bian, H., Bian, Y., Li, J., Li, Y., Ma, Y., Shao, X., et al. (2018). Peer instruction in a physiology laboratory course in China. *Adv. Physiol. Educ.* 42, 449–453. doi: 10.1152/advan.00153.2017

Bock, A., Kniha, K., Goloborodko, E., Lemos, M., Rittich, A. B., Möhlhenrich, S. C., et al. (2021). Effectiveness of face-to-face, blended and e-learning in teaching the application of local anaesthesia: a randomised study. *BMC Med. Educ.* 21:137. doi: 10.1186/s12909-021-02569-z

Chen, M., Ye, L., and Weng, Y. (2022). Blended teaching of medical ethics during COVID-19: practice and reflection. *BMC Med. Educ.* 22:361. doi: 10.1186/s12909-022-03431-6

Chen, J., Zhou, J., Wang, Y., Qi, G., Xia, C., Mo, G., et al. (2020). Blended learning in basic medical laboratory courses improves medical students' abilities in self-learning, understanding, and problem solving. *Adv. Physiol. Educ.* 44, 9–14. doi: 10.1152/advan.00076.2019

Cho, H. J., Zhao, K., Lee, C. R., Runshe, D., and Krousgrill, C. (2021). Active learning through flipped classroom in mechanical engineering: improving students' perception of learning and performance. *Int. J. STEM Educ.* 8:46. doi: 10.1186/s40594-021-00302-2

Daniel, M., Gordon, M., Patricio, M., Feng, C. P., Lyu, J., and Xu, S. L. (2021). An update on developments in medical education in response to the COVID-19 pandemic: a BEME scoping review: BEME guide no. 64. *Med. Teacher* 43, 253–271. doi: 10.1080/0142159X.2020.1864310

Diel, R. J., Yom, K. H., Ramirez, D., Alawa, K., Cheng, J., Dawoud, S., et al. (2021). Flipped ophthalmology classroom augmented with case-based learning. *Digit. J. Ophthal.* 27, 1–5. doi: 10.5693/djo.01.2021.01.004

Dooley, L. M., Frankland, S., Boller, E., and Tudor, E. (2018). Implementing the flipped classroom in a veterinary pre-clinical science course: student engagement, performance, and satisfaction. *J. Vet. Med. Educ.* 45, 195–203. doi: 10.3138/jvme.1116-173r Epub 2018 Feb 2

Fatima, S. S., Arain, F. M., and Enam, S. A. (2017). Flipped classroom instructional approach in undergraduate medical education. *Pak. J. Med. Sci.* 33, 1424–1428. doi: 10.12669/pjms.336.13699

Goldberg, L. R., and Crocombe, L. A. (2017). Advances in medical education and practice: role of massive open online courses. *Adv. Med. Educ. Pract.* 8, 603–609. doi: 10.2147/AMEP.S115321

Granero Lucchetti, A. L., Ezequiel, O. D. S., Oliveira, I. N., Moreira-Almeida, A., and Lucchetti, G. (2018). Using traditional or flipped classrooms to teach "geriatrics and gerontology"? Investigating the impact of active learning on medical students' competences. *Med. Teacher* 40, 1248–1256. doi: 10.1080/0142159X.2018.1426837. Epub 2018 Jan 21

Guillén-Gámez, F. D., Gómez-García, M., and Ruiz-Palmero, J. (2024). Competencia digital en labores de Investigación: predictores que influyen en función del tipo de universidad y género del profesorado de Educación Superior. *Pixel-Bit. Revista De Medios Y Educación.* 69, 7–34. doi: 10.12795/pixelbit.99992

Hameed, T., Husain, M., Jain, S. K., Singh, C. B., and Khan, S. (2020). Online medical teaching in COVID-19 era: experience and perception of undergraduate students. *Maedica* 15, 440–444. doi: 10.26574/maedica.2020.15.4.440

Liu, Q., Peng, W., Zhang, F., Hu, R., Li, Y., and Yan, W. (2016). The effectiveness of blended learning in health professions: systematic review and meta-analysis. *J. Med. Internet Res.* 18:e2. doi: 10.2196/jmir.4807

MacNeill, H., Masters, K., Nemethy, K., and Correia, R. (2023). Online learning in health professions education. Part 1: teaching and learning in online environments: AMEE guide no. 161. *Med. Teacher* 46, 1–14. doi: 10.1080/0142159X.2023.2197135

McLaughlin, J. E., Gharkholonarehe, N., Khanova, J., Deyo, Z. M., and Rodgers, J. E. (2015). The impact of blended learning on student performance in a cardiovascular pharmacotherapy course. *Am. J. Pharm. Educ.* 79:24. doi: 10.5688/ajpe79224

Palacios-Rodríguez, A., Llorente-Cejudo, C., Lucas, M., and Bem-haja, P. (2025). Macroevaluación de la competencia digital docente. *Estudio DigCompEdu en España y Portugal. RIED-Revista Iberoamericana de Educación a Distancia* 28:177–196. doi: 10.5944/ried.28.1.41379

Qutob, H. (2022). Effect of flipped classroom approach in the teaching of a hematology course. *PLoS One* 17:e0267096. doi: 10.1371/journal.pone.0267096

Rizk, S. H. (2018). Challenges to laboratory hematology practice: Egypt perspective. *Int. J. Lab. Hematol.* 40, 126–136. doi: 10.1111/ijlh.12834

Rotellar, C., and Cain, J. (2016). Research, perspectives, and recommendations on implementing the flipped classroom. *Am. J. Pharm. Educ.* 80:34. doi: 10.5688/ajpe80234

Shang, F., and Liu, C. Y. (2018). Blended learning in medical physiology improves nursing students' study efficiency. *Adv. Physiol. Educ.* 42, 711–717. doi: 10.1152/advan.00021.2018

Talan, T., Doğan, Y., and Kalinkara, Y. (2024). Digital natives' Mobile learning adoption in terms of UTAUT-2 model: a structural equation model. *Innoeduca Int. J. Technol. Educ. Innov.* 10, 100–123. doi: 10.24310/ijtei.101.2024.17440

Vallée, A., Blacher, J., Cariou, A., and Sorbets, E. (2020). Blended learning compared to traditional learning in medical education: systematic review and meta-analysis. *J. Med. Internet Res.* 22:e16504. doi: 10.2196/16504

Zeng, J., Liu, L., Tong, X., Gao, L., Zhou, L., Guo, A., et al. (2021). Application of blended teaching model based on SPOC and TBL in dermatology and venereology. *BMC Med. Educ.* 21:606. doi: 10.1186/s12909-021-03042-7

Zhang, W. R., Wang, K., Yin, L., Zhao, W. F., Xue, Q., Peng, M., et al. (2020). Mental health and psychosocial problems of medical health workers during the COVID-19 epidemic in China. *Psychother. Psychosom.* 89, 242–250. doi: 10.1159/000507639

Zhang, X. M., Yu, J. Y., Yang, Y., Feng, C. P., Lyu, J., and Xu, S. L. (2019). A flipped classroom method based on a small private online course in physiology. *Adv. Physiol. Educ.* 43, 345–349. doi: 10.1152/advan.00143.2018