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An online flipped classroom approach improves the physiology score and subsequent course scores of the top performing students.

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Y. X. and Z. L. conceived and designed research; Y. X., M. J., Y. X., and Y. H. analyzed data and interpreted results; Y. X. drafted manuscript; C. C., D. F., and Z. L. edited and revised manuscript; Y. X., C. C., M. J., Y. X., Y. H., D. F., and Z. L. approved final version of manuscript.

Running Title

Teaching Effect of Physiological Online Flipped Classroom

Snapshot description

An online flipped classroom approach achieved the same teaching effect as online live teaching but had a more positive impact on high-achieving students. The positive impact was not only in Physiology but also in subsequent courses where logical thinking prevailed. However, for low-achieving students, the effect of online live teaching was better.

ABSTRACT

Online Flipped Classroom (OFC) has emerged as a new teaching method in universities worldwide, which combines asynchronous and synchronous online learning. OFC differs from the traditional flipped classroom as it does not involve face-to-face interaction between teachers and students. Instead, the class meeting is conducted online, and it is focused on active and collaborative learning (e.g., discussion，rather than lecturing). To evaluate the effectiveness of the Physiology OFC, we compared it with online live teaching (OLT) offered in the same school and semester. We analyzed the exam scores of the Physiology course as well as the scores for other courses offered in the same semester and after the Physiology course. We categorized the top 27% of the exam-takers as high-achieving students and the bottom 27% as low-achieving students. Our analysis found no statistically significant difference between OFC and OLT in terms of overall exam scores for all students. However, high-achieving students in OFC scored higher on the total exam score and short answer questions (SAQs) but the score of case study questions (CSQs) of low-achieving students was lower. Furthermore, students in OFC scored higher in Medical Immunology and courses dominated by logical thinking such as Pharmacology and Diagnostics than students in OLT. In conclusion, our findings suggest that OFC can achieve the same teaching effectiveness as OLT, with a more positive impact on high-achieving students. The positive impact extends beyond the Physiology course to other courses where logical thinking is critical. However, the

lower performance of low-achieving students in CSQs highlights the need for further research to determine the reasons for their lower performance and potential strategies to improve their learning outcomes.

New & Noteworthy statement

An online flipped classroom approach achieved the same teaching effect as online live teaching but had a more positive impact on high-achieving students. The positive impact was not only in Physiology but also in subsequent courses where logical thinking prevailed. However, for low-achieving students, the effect of online live teaching was better.

Keywords

Online Flipped Classroom; Online Live Teaching; Teaching Effect; Medical Education; Physiology

INTRODUCTION

The flipped classroom is a teaching approach that involves reversing the process of knowledge transfer and mastery, from “teachers and students” to “between teacher and students” and rearranging the classroom schedules (1). It effectively expands the teaching covering and contents (2), thereby achieving a revolutionary change from conventional teaching approaches. Originating in 2000 (3), the flipped classroom has gained rapid momentum, and numerous studies have been conducted to evaluate its impact on the student qualities and competencies.

Studies have demonstrated that the flipped classroom has positive implications for the improvement of students' autonomous learning, critical thinking, interpersonal communication, and innovative planning abilities (4, 5). Additionally, research has investigated the long- and short-term impact of the flipped classroom on student learning processes and outcomes. For example, Bouwmeester et al. found that students in a flipped classroom were more interactive in class, required less time investment when preparing for the end-of-course exam, and perceived higher self-efficacy compared to students in traditional classrooms. However, comparison of long-term measurements (retention of knowledge and self-efficacy) showed similar outcomes for students in traditional classrooms and flipped classrooms (6).

In China, the flipped classroom was first introduced in 2012 (7), and in the past 10

years, its application scope in the Chinese higher education system has been expanded, particularly in the field of medical education. Both in basic medical teaching and clinical practice training, the flipped classroom has been widely explored and continuously innovated to improve the teaching effect. The Department of Physiology at Xiangya School of Medicine carried out flipped classroom teaching of Physiology using national quality open courses (NQROC) (http://www.icourse163.org/course/CSU-1001930016) and obtained better results than traditional face-to-face classes (8). However, this previous flipped classroom model included offline classroom lectures, with partial knowledge transfer still from teacher to students.

During the COVID-19 pandemic in 2020, the Department of Physiology at Xiangya School of Medicine explored and implemented a new online flipped classroom (OFC) teaching model that was completely based on NQROC. In this model, students learned knowledge independently before the online class. Instead of elaborating the difficult and key points in the class, teachers provided guided questions and answers to achieve an effective teacher-student interaction. The OFC required students to actively learn and master the knowledge, fully demonstrating learning autonomy. To evaluate the effect of OFC, the end-of-course exam scores of 258 clinical medicine major students at Xiangya School of Medicine were analyzed. These students were randomly assigned to two groups, with 140 students taught by OFC and 118 students

taught by online live teaching (OLT) as the control group. Through the analysis of teaching results (end-of-course exam scores) and the learning process (NQROC learning situation), the effect of OFC was evaluated.

METHODS

Students Participating in the Study.

In China, senior high school students, who passed the National College Entrance Examination (NEMT) above certain scores, are selected to enter medical school for a five-year undergraduate clinical medical education. Medical students spend the first academic year in natural science courses, the second year and a half in basic medicine, and the remaining two years and a half in clinical training and internships. There are two semesters per year-spring and fall, for a total of ten semesters during the undergraduate program. Medical students study Physiology in the 4^{th} semester (i.e., second academic year, second semester).

258 Xiangya School of Medicine 2018 clinical medicine-major students were selected as study participants. They were randomly assigned to two groups, 140 students in the OFC group and 118 students in the OLT group. They were tracked and analyzed by name and student ID as unique identifiers. The course requirements were the same for both groups. All participants had given informed consent to the study. Our research had received approval from the Review Office of Medical Teaching and Teaching

Research, Xiangya School of Medicine, Central South University of China, the designated authority overseeing undergraduate education and teaching research of medical students.

The 258 students were all from the same major and grade. The age (years) of the two groups were 20.0±0.9 and 20.1±0.5 respectively, and the difference was not statistically significant (t= -1.439, P=0.151). No statistically significant difference was revealed concerning the proportion of males (χ^2=0.063, P=0.802), which was 42.14% and 43.59% respectively.

Introduction to Physiology Teaching

In the spring semester of 2020, relying on an Internet-based instant messaging software Tencent QQ (Tencent, Shenzhen, China), an audio and video conferencing software Tencent Meeting (Tencent, Shenzhen, China), and a higher education course resource sharing platform i-Course (Higher Education Press Ltd., Beijing, China), two different online teaching models, OFC and OLT, were provided to clinical medicine major 2018 entry students. Both are composed of 3 teaching links: before class, during class, and after class.

The online flipped classroom teaching model (OFC)

Before class, students learned independently in accordance with the learning tasks and

objectives announced by the teacher in advance in the QQ group. For example, in class “the material transport function of the cell membrane”, the pre-class learning tasks were: ①Learning materials: Chapter 2, Sections 1 and 2; and ②Watching videos: 2.1, 2.2. The learning objectives became proficient in several different mechanisms of moving substances across cell membranes, which included simple diffusion, facilitated diffusion, and active transport. Additionally, students were expected to be able to identify the types of substances that moved by simple diffusion and gained a basic understanding of how substances moved in and out of cells. Finally, students were asked to review the composition and structure of cell membranes.

During class, live online lectures were replaced with problem-driven teacher-student and student-student interaction, emphasizing that students were the subject of education for autonomous knowledge exploration, transfer and mastery.

Specific teaching implementation process (Figure 1):

① Independent study before class: Students studied NQROC videos autonomously according to the learning tasks and objectives given by the teacher in advance of class through the QQ group for knowledge transfer. The teacher collected questions from students and answered individual questions in writing through the QQ group. The questions suitable for wide-ranging discussion would be selected for the QQ group to encourage

thinking and preparation by students.

② Teacher-student interaction during class: Teachers interacted with students in the QQ group according to the class schedule. During the 2 credit hours of classroom teaching time, 1st credit hour of online group discussion was conducted under the guidance of the teacher, in which the teacher continuously provided guided questions about the key points of learning knowledge, stimulated thinking by students, promoted close teacher-student interaction and student-student interaction, and supported students to master the knowledge thoroughly. In the 2nd credit hour, the teacher mainly answered individualized questions by students without group discussions.

③ Feedback from teachers after class: Teacher provided real-time feedback through online learning platform to students, urged students to learn independently, and tested learning effects by weekly NQROC online quizzes.

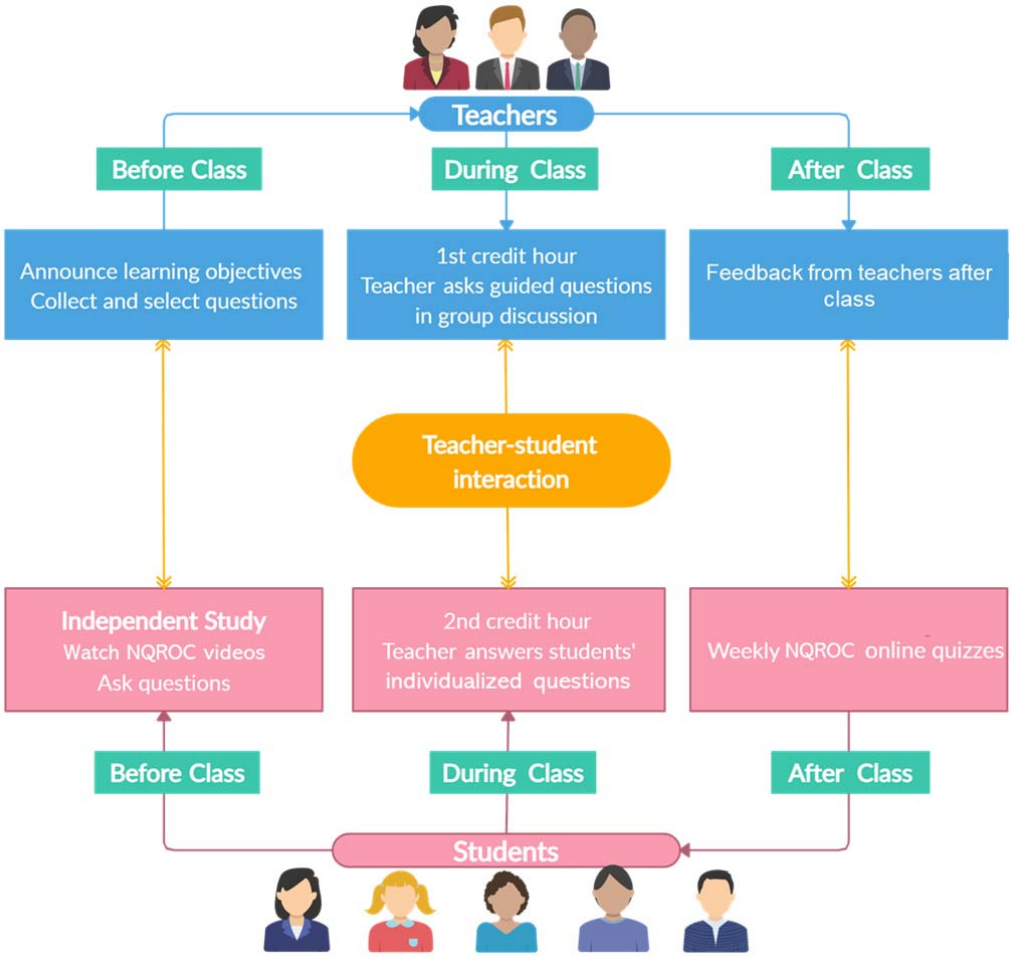

Figure 1. Specific teaching implementation process in the Online Flipped Classroom (OFC). It consisted of 3 links: ①Independent study before class: The teacher released learning tasks and objectives, and students watched videos, read textbooks, and asked questions; ②Teacher-student interaction during class: 1st credit hour of online group discussion and 2nd credit hour of individualized questions; ③Feedback from teachers after class: The teacher tracked the learning effect through quizzes and other methods.

Each OFC schedule included three links mentioned above. The time spent by students before and after the class was not quantified. One class lasted 90 minutes, and there

were 39 Physiology classes in one semester. The students in the OFC group studied in this way for the entire semester.

In OFC, there were 118 videos in NQROC, total length of 1301 min. Students were requited to watch no less than 900 min of video in total. In fact, most students watched more than 900 min of video. Thus, video viewing time beyond the required 900-minute was referred to as “overtime”, which showed self-engagement of students in autonomous online learning. In addition, students were encouraged to post questions or answers to questions from other students on the NQROC discussion board. All questions and answers were tracked and recorded but were not counted toward the academic score of any student. Most students participated in the questions and answers. The participation rate of the students reflected autonomous learning input of students.

The online live teaching model (OLT)

Teachers used Tencent Meeting to teach live online, and the teaching method was close to traditional face-to-face classes:

① Before class: teacher released the course schedule and learning objectives to students in QQ group.

② During class: teacher delivered the course contents online through Tencent Meeting.

③ After class: teacher provided weekly online quizzes to test learning effect.

The end-of-course exam of Physiology was held offline in the first week of the second semester after the completion of physiology teaching semester and summer vacation. Fifty multiple-choice questions (MCQs) (worth 50 points), eight short-answer questions (SAQs) (worth 24 points), and three case study questions (CSQs) (worth 26 points) made up the 100-point exam. To eliminate the subjective bias in the judgment by teachers, SAQs and CSQs were scored by two teachers anonymously through the online marking system. The names of student and other marking teacher were not identified during marking, and the final score of each question was the average of two scores by different teachers. The difficulty index and discrimination index of the test were 0.63 and 0.38, indicating that the testing paper had a moderate difficulty and a good differentiation. The end-of-course exam scores in our study were all exported from the university undergraduate grade management platform.

Statistical Analysis

The data analyzed by our study is as follows:

① To investigate the short-term impact of OFC, we compared Physiology end-of-course exam scores, scores on different question types (MCQs, SAQs and CSQs), and the end-of-course exam scores on other medical specialty courses in the 4^{th} semester (Medical Immunology, Medical

Microbiology and Medical Parasitology) in two groups. The study referred to the conclusion of Kelley et al. that "27th and 73rd quantiles are the most distinguishing quantiles" (9, 10), defining the top 27% of the Physiology exam scores as high-achieving students and the bottom 27% as low-achieving students (38 students in OFC and 32 students in OLT).

In addition, we compared the end-of-course exam scores of the two groups in Biochemistry, Histology & Embryology in the 3rd semester to evaluate the comparability of the students before the 4th semester.

To examine the long-term impact of OFC, we compared Pharmacology and Pathology in the 5th semester and Diagnostics in the 6th semester. Internal Medicine and Surgical Sciences were the main clinical courses, which were taught usually in the 7th and 8th semesters. The students were further divided into different teaching classes at the 7th and 8th semesters, and the end-of-course exams used no longer the same questions. Therefore, these courses had less comparability and were not compared in this study.

② NQROC learning data (video viewing overtime, the number of messages that were sent to the discussion board and online quiz scores) for students in OFC were collected to determine whether there were differences in NQROC learning situation between the high- and low-achieving students.

The data were coded, entered, and analyzed using the SPSS statistical package, version 25.0 (SPSS Inc., Chicago, IL). The scores of some courses and NQROC learning data did not obey Gaussian distribution. So, they were represented by the

median of the central tendency and the upper and lower quartiles of the discrete trend, namely *M (P25, P75)*, and compared using the Mann-Whitney U test. Enumeration data were expressed as n (%). Chi-square test was used for sex ratio and the proportion of high- and low-achieving students, who watched videos beyond the required 900 minutes. $P<0.05$ indicated that differences were statistically significant.

RESULTS

Basic knowledge level of students before studying Physiology

To check if two groups of students were comparable, the Mann-Whitney U test was performed to compare the scores of courses before studying Physiology, Histology & Embryology and Biochemistry, in two groups for all students, high- and low-achieving students respectively. The differences were not statistically significant (Table 1). This suggested no difference in the level of basic knowledge and learning ability of two groups of students before studying Physiology. The two groups of students had high comparability.

Table 1. Verification of the comparability of two groups. To observe whether the basic knowledge and learning ability of two groups are equivalent, we used the Mann-Whitney U test to compare the scores of the courses before studying Physiology. These courses are professional courses that students must take before studying medical physiology courses. The table showed the students' end-of-course exams scores (Only one exam per course), obtained through the school's score management platform.

OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

Courses	Students	OFC	OLT	*Z*	*P*
Histology & Embryology	All physiology students 140 vs 118	71.00(59.00,80.00)	68.00(58.00,75.00)	-1.921	0.055
	High-achieving physiology students 38 vs 32	83.00(75.75,88.00)	77.50(73.25,82.50)	-1.946	0.052
	Low- achieving physiology students 38 vs 32	53.50(47.00,63.00)	52.50(45.00,59.50)	-0.965	0.334
Biochemistry	All physiology students 140 vs 118	72.00(50.50,82.00)	70.00(57.75,80.00)	-0.515	0.606
	High-achieving physiology students 38 vs 32	86.00(77.50,91.00)	84.00(77.25,86.75)	-1.144	0.252
	Low- achieving physiology students 38 vs 32	47.00(41.50,55.50)	53.00(43.00,64.00)	-1.060	0.289

Comparison of Physiology scores in two groups

To observe the teaching effect of OFC, we used the Mann-Whitney U test to compare the scores of MCQs, SAQs, CSQs and total scores of all students in OFC and OLT. There was no statistically significant difference (P>0.05) (Table 2).

Table 2. Comparison of Physiology scores of all students in two groups. To observe the teaching

effect of OFC, we used the Mann-Whitney U test to compare Physiology scores of all students. The table showed the students' end-of-course exam scores, obtained through the school's score management platform. The exam was scored out of 100 points and consists of 50 Multiple Choice Questions (MCQ) (50 points), 8 Short Answer Questions (SAQ) (24 points) and 3 Case Study Questions (CSQ) (26 points). OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

	OFC (n=140)	OLT (n=118)	*Z*	*P*
Total score (100)	70.25(54.13，80.50)	65.25(54.75，76.25)	-1.254	0.210
Score of MCQs (50)	37.00(30.25，42.00)	36.00(30.00，42.00)	-0.632	0.527
Score of SAQs (24)	14.50(9.50,19.50)	12.50(9.38，18.00)	-1.658	0.097
Score of CSQs (26)	17.00(13.00，19.50)	16.00(13.38，18.13)	-1.078	0.281

In OFC, the high-achieving students received a significantly higher total scores and SAQs scores than those in OLT. Also, the difference between the scores of MCQs and CSQs were not statistically significant between two models for high-achieving students (P>0.05) (Table 3).

Table 3. Comparison of Physiology scores of high-achieving students in two groups. To further observe the teaching effect of OFC, we used the Mann-Whitney U test to compare Physiology scores of high-achieving students. The table showed the students' end-of-course exam scores, obtained through the school's score management platform. The exam was scored out of 100 points and consists of 50 Multiple Choice Questions (MCQ) (50 points), 8 Short Answer Questions (SAQ) (24 points) and 3

Case Study Questions (CSQ) (26 points). OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

	OFC(n=38)	OLT (n=32)	*Z*	*P*
Total score (100)	83.75((81.50, 87.50)	81.50(78.50, 84.88)	-2.803	0.005**
Score of MCQs (50)	44.00(42.00, 46.00)	44.00(41.25, 46.00)	-0.614	0.539
Score of SAQs (24)	20.50(19.50, 21.63)	19.00(17.25, 20.50)	-2.803	0.005**
Score of CSQs (26)	20.50(18.88, 21.63)	19.25(18.00, 21.50)	-1.466	0.143

**$P<0.01$

In OFC, the score of CSQs of the low-achieving students was lower than that in OLT ($P<0.05$), and there was no significant difference between the scores of MCQs, SAQs and the total score between two models for low-achieving students ($P>0.05$) (Table 4).

Table 4. Comparison of Physiology scores of low-achieving students in two groups. To further observe the teaching effect of OFC, we used the Mann-Whitney U test to compare Physiology scores of low-achieving students. The table showed the students' end-of-course exam scores, obtained through the school's score management platform. The exam was scored out of 100 points and consists of 50 Multiple Choice Questions (MCQ) (50 points), 8 Short Answer Questions (SAQ) (24 points) and 3 Case Study Questions (CSQ) (26 points). OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

	OFC (n=38)	OLT (n=32)	*Z*	*P*
Total score (100)	44.75(38.38,52.13)	50.50(46.00,52.00)	-1.864	0.062
Score of MCQs (50)	27.50(24.75,30.00)	28.00(26.00,30.75)	-0.966	0.334
Score of SAQs (24)	5.50(4.38,9.00)	7.25(5.13,9.50)	-1.713	0.087
Score of CSQs (26)	11.00(9.00,13.13)	12.50(10.63,14.50)	-2.144	0.032*

*P<0.5

These results illustrated that on the whole, OFC and OLT had the same effect. However, for the high-achieving students, OFC was more effective than OLT, while for the low-achieving students, on the contrary, OLT had a better result.

Comparison of scores of the major courses in the same semester as Physiology

Since OFC relied more on autonomous learning, the students needed to spend more time before class to prepare for class interactions, which might interfere with learning in other courses in the semester. Thus, we analyzed end-of-course exams scores of the other major courses of this semester, which OLT was utilized by all students. There were no statistically significant differences in scores in either Medical Microbiology or Medical Parasitology, except for Medical Immunology, where OFC group earned higher scores than OLT (Table 5). This showed that OFC might help students perform better in other classes during the same semester as opposed to having a negative impact as suggested by another study (11).

Table 5. Comparison of the scores of the major courses in the same semester as Physiology. We employed the Mann-Whitney U test to compare the courses in the same semester as Physiology since students at OFC must dedicate time to autonomous learning, which may have a detrimental effect on the study of other courses in the same semester. These courses are professional courses that students must take. The table displayed the students' end-of-course exams scores (only one exam per course), obtained through the school's score management platform. OFC stands for the online flipped classroom teaching model, while OLT is the online live teaching model.

Courses	Students	OFC	OLT	*Z*	*P*
Immunology	All physiology students 140 vs 118	80.00(65.50,88.00)	77.00(62.75,86.00)	-2.041	0.041*
	High-achieving physiology students 38 vs 32	91.00(87.00,93.00)	87.00(83.25,90.00)	-2.883	0.004**
	Low- achieving physiology students 38 vs 32	55.00(48.88,68.25)	59.00(51.00,63.00)	-0.227	0.821
Microbiology	All physiology students 140 vs 118	67.00(57.75,77.75)	66.50(56.50,76.88)	-0.800	0.424
	High-achieving physiology students 38 vs 32	82.50(76.75,85.50)	80.50(72.00,85.00)	-1.097	0.273
	Low- achieving physiology students 38 vs 32	54.00(51.25,58.50)	54.50(49.00,63.50)	-0.591	0.554
Parasitology	All physiology students	78.00(67.00,83.75)	76.50(66.50,83.88)	-0.666	0.505

140 vs 118				
High-achieving physiology students				
	86.50(81.25,89.50)	86.50(83.00,88.88)	-0.030	0.976
38 vs 32				
Low- achieving physiology students				
	65.00(58.13,70.88)	63.00(59.50,72.50)	-0.182	0.855
38 vs 32				

342 *P<0.5, **P<0.01

343

344 **Comparison of scores of the major courses after studying Physiology**

345 Physiology is the science of life, with the aim to illuminate the working mechanism of
346 the healthy body. It also helps us to determine what goes wrong in diseases and
347 facilitates the development of new treatments and guidelines for maintaining human
348 and animal health (12). Besides that, Physiology is a pre-requisite course for all health
349 allied programs (13). Therefore, the effect of Physiology study may have an impact on
350 the subsequent medical courses. We further analyzed the effect of two different
351 Physiology online teaching models on subsequent learning outcomes of major
352 medical courses. The results showed that the Pharmacology and Diagnostics scores of
353 OFC high-achieving students were higher than those of OLT. There was no
354 statistically significant difference in the scores of Pathology (Table 6).

355

356 **Table 6. Comparison of two groups in the courses after studying Physiology.** To observe the
357 long-term effects of Physiology OFC, we employed the Mann-Whitney U test to compare the scores of

two groups in the courses after studying Physiology. These courses are professional courses that students must take. The table displayed the students' end-of-course exams scores (only one exam per course), obtained through the school's score management platform. OFC stands for the online flipped classroom teaching model, while OLT is the online live teaching model.

Courses	Students	OFC	OLT	*Z*	*P*
Pharmacology	All physiology students 140 vs 118	73.00(56.88,82.13)	69.50(52.75,79.75)	-1.069	0.285
	High-achieving physiology students 38 vs 32	84.00(80.50,89.25)	80.50(73.50,86.00)	-2.150	0.032*
	Low-achieving physiology students 38 vs 32	46.00(29.75,60.75)	50.50(35.50,62.00)	-0.867	0.386
Pathology	All physiology students 140 vs 118	84.50(78.00,89.00)	83.50(75.00,88.00)	-1.050	0.294
	High-achieving physiology students 38 vs 32	90.00(86.75,92.25)	89.50(87.00,92.00)	-0.117	0.907
	Low-achieving physiology students 38 vs 32	70.25(60.38,79.50)	70.50(62.00,79.50)	-0.131	0.895
Diagnostics	All physiology students 140 vs 118	68.00(58.00,76.25)	65.25(57.00,73.81)	-1.195	0.232
	High-achieving physiology students 38 vs 32	79.75(73.50,84.25)	76.25(70.63,78.25)	-2.206	0.027*

Low-achieving physiology students				
	49.50(43.38,58.63)	55.00(46.75,60.00)	-1.122	0.262
38 vs 32				

362 *P<0.5, **P<0.01

363

364 **NQROC learning situation of students in OFC**

365 In OFC, the NQROC online quiz scores, the number of messages which were sent to
366 the discussion board, and the video viewing time beyond the required 900-minute of
367 the high-achieving students were significantly higher than those of the low-achieving
368 students (Table 7). 86.84% of high-achieving students watched NQROC videos
369 for >900 min, while 34.21% of low-achieving students did not complete the minimum
370 requirement (χ^2=4.659, P=0.031), indicating that the high-achieving students were
371 more engaged in online autonomous learning than that in low-achieving students.

372

373 **Table 7. Comparison of NQROC learning data of high- and low-achieving students in OFC.** We
374 used the Mann-Whitney U test to compare the NQROC learning data of high- and low-achieving
375 students, which partially illustrated the students' online autonomous learning input, to determine
376 whether there are differences in NQROC learning situation between the high- and low-achieving
377 students. The NQROC learning data comprised the video viewing overtime, number of messages which
378 were sent to the discussion board and NQROC online quiz scores. The data came from the NQROC
379 platform-i-Course. NQROC stands for national quality resource of open courses.

NQROC learning data	High-achieving	Low-achieving	*Z*	*P*

	physiology students (n=38)	physiology students (n=38)		
Online quiz scores	98.89(96.70,99.84)	94.40(77.30,97.88)	-4.240	<0.0001***
Number of messages sent to the discussion board	11(6,20)	6(-2,11)	-2.951	0.003**
Overtime of video viewing (min)	459 (115, 870)	311(-356, 772)	-1.330	0.184

**P<0.01, ***P<0.001

DISCUSSION

The research findings indicate that the implementation of an online flipped classroom (OFC) model had a positive impact on the academic performance of high-achieving students. The positive impact was evident not only in Physiology where OFC was implemented but also in subsequent courses where critical thinking skills were emphasized, even in cases where OFC was not utilized. Previous literature has reported varying effects of flipped classrooms (14, 15), with some studies indicating a lack of significant impact on student academic performance (16, 17) and potential underperformance compared to traditional classroom settings (18). This study focused specifically on an entirely web-based OFC model, which required students to engage in more autonomous and independent learning. While prior research has speculated that the teaching effectiveness of online flipped classrooms would be similar to traditional face-to-face classrooms by collecting student feedback from students (19),

the current study provides objective evidence by directly comparing the exam scores of OFC and online live teaching (OLT) and finding no significant difference. OLT has been shown to be an effective online education form that is comparable to traditional classroom instruction in previous studies (20, 21). Therefore, the results of this study provide further support for the feasibility and effectiveness of OFC as an online teaching model.

In this study, the prerequisite courses of Histology & Embryology and Biochemistry were initially evaluated to confirm that there were no significant differences between the two groups. Results indicated that high-achievers in OFC had higher total scores than those in OLT, which may be due to their superior self-regulation skills (22, 23). Further analysis revealed that the disparity in scores was primarily attributable to SAQs, which promote Test-Enhanced Learning (TEL, the phenomena that tests enhance retention of learned information beyond simple studying) (24) and require students to generate correct answers on their own, as opposed to MCQs which only require identification of correct answers (25). SAQs assess students' ability to recall, understand and apply knowledge, similar to the teacher-student interactions in OFC. While the workload and time consumption in OFC may be increased (11), it did not negatively impact the performance of other courses in the same semester. In fact, OFC even improved performance overall and among high-achievers in Medical Immunology, indicating that it has the potential to enhance academic performance.

Several studies have demonstrated that the retention of knowledge in flipped classroom students is comparable to that of traditional classroom students (26, 27). For instance, Bouwmeester et al. found that students in a flipped classroom teaching setting performed equally well in questions requiring factual understanding and those involving the application of relevant knowledge in Hematology and Oncology courses in the 2nd year medical program (6). Since physiological knowledge forms the basis for comprehending the normal functional activities of the body and the mechanisms of abnormal activities under disease conditions (12, 13), it is considered the "logic of life" (28). So, mastering physiological knowledge may affect the study of subsequent medical courses. To evaluate the long-term teaching effect of the OFC approach to physiology, the impact on subsequent learning outcomes of major medical courses, such as Pharmacology, Pathology, and Diagnostics, was analyzed. While no overall difference was observed in the performance of these courses in the offline face-to-face classroom teaching model, high-achieving students in OFC scored higher in Pharmacology and Diagnostics than in OLT. Since Pharmacology and Diagnostics are considered logical thinking-dominated subjects (29, 30), whereas Pathology is considered morphology-dominated (31), the findings suggest that Physiology OFC can enhance the academic performance of high-achieving students not only in the physiology course through OFC but also in subsequent logical thinking-dominated courses.

Drawing from Bloom's Taxonomy, the lower-level cognitive processes of knowledge and comprehension are easily attained by students, whereas higher-level learning, such as application, analysis, synthesis, and evaluation, is better achieved under the guidance of a teacher (32, 33). The flipped classroom, a teaching method where students engage with reading materials or video lectures to learn basic knowledge before class and use class time for exercises and guided application of knowledge (34), promotes deep understanding through higher-level learning (35). Studies have shown that flipped classrooms provide teachers with the opportunity to spend less time transferring factual knowledge and more time on inquiry-based activities and feedback (6), which is increasingly popular in higher education across STEM (Science, Technology, Engineering and Mathematics) (36–39) and health-related subjects (16, 40–42). Although previous research has demonstrated that the flipped classroom approach has a positive impact on student learning outcomes and experiences (18, 43–46), its effect on low-achieving students and those with low self-discipline in learning has been a matter of concern. Some studies discovered that the flipped classrooms narrowed the achievement gap between high- and low-achieving students and improved more significantly the performance of low-achieving students (43–45). However, other studies demonstrated that flipped classrooms had a positive effect on students' performance in the high- and middle- achieving students, with little effect in the low-achieving students (46), and even negative effect in

students with low self-discipline in learning (18). The OFC builds on the advantages of the offline flipped classroom by promoting autonomous learning, assimilation, and mastery of knowledge, improving comprehensive learning ability, and achieving high scores in examinations. Compared with OLT where the teacher did not directly observe the attitude of students, in the OFC, students might keep up with the teaching rhythm. Through NQROC self-learning basic knowledge, low-level learning of memory and comprehension was completed. In class, teacher proposed interesting and targeting questions collected from students or prepared by the teacher in a pre-designed sequence and guided students to discuss online to inspire thinking by students. Teachers participated in the discussion by students throughout the whole process, summarized opinions through discussion, and gave students timely affirmations, corrections, and guidance. Therefore, students obtained correct answers through continuous reading, thinking and discussion. Through this kind of online Socratic questioning and discussion, the comprehension of the knowledge before class was strengthened, the closed-loop of positive feedback of learning-reflection-re-learning was achieved, and the understanding and mastery of knowledge were ensured. However, same as the persistent concerns about low-achieving students (47, 48), the OFC may worsen the low self-motivation of low-achieving students and affect their exam scores. Despite the strengths of the OFC, it was found to be less effective than the OLT for low-achieving students, as their score of CSQs was lower than that of OLT.

In this study, an investigation of the online learning situation of high- and low-achieving students was conducted using the NQROC learning data of OFC. The results demonstrated a positive relationship between student autonomy and academic success in OFC, as high-achieving students outperformed their low-achieving peers in online quizzes, messages sent to the discussion board, and total video-watching time. However, the online learning environment presented some challenges that may compromise teacher-student interactions and supervision, as the teacher's ability to monitor the students' learning progress may be limited (18, 49-51). Additionally, the success of OFC is contingent upon students' motivation and autonomy, which may be hindered among low-achieving students who have weaker foundations and lower motivation (47, 48). The CSQs in Physiology exam required higher-order cognitive activities (52), and the discussions during class of OFC focused on challenging topics, which required sufficient knowledge reserves. However, low-achieving students, who were less motivated and resistant to team learning, were unable to grasp the concepts effectively, resulting in lower CSQ scores than OLT. This suggests that the benefits of OFC may not be entirely realized among low-achieving students, who require additional support to improve their performance in the online environment. Prior research has revealed similar results in traditional flipped classrooms, highlighting the importance of self-regulated learning skills for academic success (53–56). Hence, adjustments to the flipped classroom strategy and increased attention to actual student

participation and learning outcomes should be made according to the differences in learning ability. In doing so, the flipped classroom can effectively improve medical education. In contrast, OLT is teacher-centered, with less student participation and lower requirements for student autonomy than flipped classrooms. Therefore, OLT may be more suitable for students with poor learning autonomy who need to master foundational knowledge.

Limitations

While the i-Course platform records viewing time once a video has been opened, it does not provide insights into whether the student is actively engaged with the content. Therefore, the reported "overtime" spent watching videos may not accurately reflect students' true engagement levels. To address this issue, future studies could explore more sophisticated personal learning management functions within the online learning platform, such as embedding quizzes or limiting access to other web pages during video playback. These measures could provide a more comprehensive understanding of student engagement and help to identify areas for improvement in the design and delivery of OFC.

CONCLUSIONS

Our study provides evidence supporting the feasibility and effectiveness of implementing OFC in a medical course, as demonstrated by the improvement in exam

scores. While most flipped classrooms are typically used for certain sections of a course (57), our study confirms the benefits of using OFC for the entirety of a course, and even for subsequent medical courses that rely on logical thinking. We also observed that high-achieving students benefited more from OFC than low-achieving students, who may have been negatively impacted by the autonomous nature of the learning environment. Our findings suggest that the success of OFC depends on students' learning autonomy, and thus low-achieving students require additional support from teachers to enhance their self-monitoring, supervision, and active participation in the flipped classroom. Teachers can support low-achieving students by providing appropriate praise and motivation, and actively interacting with students to ensure real participation in the flipped classroom before, during, and after class. By strengthening their self-monitoring and supervision, and actively participating in discussions, low-achieving students can fully benefit from OFC and improve their academic performance. While OFC presents a promising approach to medical education, more research is needed to further explore its effectiveness, particularly among low-achieving students.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

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Figure 1. Specific teaching implementation process in the Online Flipped Classroom (OFC).

It consisted of 3 links: ①Independent study before class: The teacher released learning tasks and objectives, and students watched videos, read textbooks, and asked questions; ②Teacher-student interaction during class: 1st credit hour of online group discussion and 2nd credit hour of individualized questions; ③Feedback from teachers after class: The teacher tracked the learning effect through quizzes and other methods.

Teachers

Before Class

Announce learning objectives
Collect and select questions

During Class

1st credit hour
Teacher asks guided questions in group discussion

After Class

Feedback from teachers after class

Teacher-student interaction

Independent Study
Watch NQROC videos
Ask questions

2nd credit hour
Teacher answers students' individualized questions

Weekly NQROC online quizzes

Before Class

During Class

After Class

Students

Table 1. Verification of the comparability of two groups. To observe whether the basic knowledge and learning ability of two groups are equivalent, we used the Mann-Whitney U test to compare the scores of the courses before studying Physiology. These courses are professional courses that students must take before studying medical physiology courses. The table showed the students' end-of-course exams scores (Only one exam per course), obtained through the school's score management platform. OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

Courses	Students	OFC	OLT	*Z*	*P*
Histology & Embryology	All physiology students 140 vs 118	71.00(59.00,80.00)	68.00(58.00,75.00)	-1.921	0.055
	High-achieving physiology students 38 vs 32	83.00(75.75,88.00)	77.50(73.25,82.50)	-1.946	0.052
	Low- achieving physiology students 38 vs 32	53.50(47.00,63.00)	52.50(45.00,59.50)	-0.965	0.334
Biochemistry	All physiology students 140 vs 118	72.00(50.50,82.00)	70.00(57.75,80.00)	-0.515	0.606
	High-achieving physiology students 38 vs 32	86.00(77.50,91.00)	84.00(77.25,86.75)	-1.144	0.252
	Low- achieving physiology students 38 vs 32	47.00(41.50,55.50)	53.00(43.00,64.00)	-1.060	0.289

Table 2. Comparison of Physiology scores of all students in two groups. To observe the teaching effect of OFC, we used the Mann-Whitney U test to compare Physiology scores of all students. The table showed the students' end-of-course exam scores, obtained through the school's score management platform. The exam was scored out of 100 points and consists of 50 Multiple Choice Questions (MCQ) (50 points), 8 Short Answer Questions (SAQ) (24 points) and 3 Case Study Questions (CSQ) (26 points). OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

	OFC (n=140)	OLT (n=118)	*Z*	*P*
Total score (100)	70.25(54.13，80.50)	65.25(54.75，76.25)	-1.254	0.210
Score of MCQs (50)	37.00(30.25，42.00)	36.00(30.00，42.00)	-0.632	0.527
Score of SAQs (24)	14.50(9.50,19.50)	12.50(9.38，18.00)	-1.658	0.097
Score of CSQs (26)	17.00(13.00，19.50)	16.00(13.38，18.13)	-1.078	0.281

Table 3. Comparison of Physiology scores of high-achieving students in two groups. To further observe the teaching effect of OFC, we used the Mann-Whitney U test to compare Physiology scores of high-achieving students. The table showed the students' end-of-course exam scores, obtained through the school's score management platform. The exam was scored out of 100 points and consists of 50 Multiple Choice Questions (MCQ) (50 points), 8 Short Answer Questions (SAQ) (24 points) and 3 Case Study Questions (CSQ) (26 points). OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

	OFC(n=38)	OLT (n=32)	*Z*	*P*
Total score (100)	83.75((81.50, 87.50)	81.50(78.50, 84.88)	-2.803	0.005**
Score of MCQs (50)	44.00(42.00, 46.00)	44.00(41.25, 46.00)	-0.614	0.539
Score of SAQs (24)	20.50(19.50, 21.63)	19.00(17.25, 20.50)	-2.803	0.005**
Score of CSQs (26)	20.50(18.88, 21.63)	19.25(18.00, 21.50)	-1.466	0.143

***P*<0.01

Table 4. Comparison of Physiology scores of low-achieving students in two groups. To further observe the teaching effect of OFC, we used the Mann-Whitney U test to compare Physiology scores of low-achieving students. The table showed the students' end-of-course exam scores, obtained through the school's score management platform. The exam was scored out of 100 points and consists of 50 Multiple Choice Questions (MCQ) (50 points), 8 Short Answer Questions (SAQ) (24 points) and 3 Case Study Questions (CSQ) (26 points). OFC is the online flipped classroom teaching model; OLT is the online live teaching model.

	OFC (n=38)	OLT (n=32)	*Z*	*P*
Total score (100)	44.75(38.38,52.13)	50.50(46.00,52.00)	-1.864	0.062
Score of MCQs (50)	27.50(24.75,30.00)	28.00(26.00,30.75)	-0.966	0.334
Score of SAQs (24)	5.50(4.38,9.00)	7.25(5.13,9.50)	-1.713	0.087
Score of CSQs (26)	11.00(9.00,13.13)	12.50(10.63,14.50)	-2.144	0.032*

*$P<0.5$

Table 5. Comparison of the scores of the major courses in the same semester as Physiology. We employed the Mann-Whitney U test to compare the courses in the same semester as Physiology since students at OFC must dedicate time to autonomous learning, which may have a detrimental effect on the study of other courses in the same semester. These courses are professional courses that students must take. The table displayed the students' end-of-course exams scores (only one exam per course), obtained through the school's score management platform. OFC stands for the online flipped classroom teaching model, while OLT is the online live teaching model.

Courses	Students	OFC	OLT	*Z*	*P*
Immunology	All physiology students 140 vs 118	80.00(65.50,88.00)	77.00(62.75,86.00)	-2.041	0.041*
	High-achieving physiology students 38 vs 32	91.00(87.00,93.00)	87.00(83.25,90.00)	-2.883	0.004**
	Low- achieving physiology students 38 vs 32	55.00(48.88,68.25)	59.00(51.00,63.00)	-0.227	0.821
Microbiology	All physiology students 140 vs 118	67.00(57.75,77.75)	66.50(56.50,76.88)	-0.800	0.424
	High-achieving physiology students 38 vs 32	82.50(76.75,85.50)	80.50(72.00,85.00)	-1.097	0.273
	Low- achieving physiology students 38 vs 32	54.00(51.25,58.50)	54.50(49.00,63.50)	-0.591	0.554
Parasitology	All physiology students	78.00(67.00,83.75)	76.50(66.50,83.88)	-0.666	0.505

140 vs 118				
High-achieving physiology students				
	86.50(81.25,89.50)	86.50(83.00,88.88)	-0.030	0.976
38 vs 32				
Low- achieving physiology students				
	65.00(58.13,70.88)	63.00(59.50,72.50)	-0.182	0.855
38 vs 32				

*P<0.5, **P<0.01

Table 6. Comparison of two groups in the courses after studying Physiology. To observe the long-term effects of Physiology OFC, we employed the Mann-Whitney U test to compare the scores of two groups in the courses after studying Physiology. These courses are professional courses that students must take. The table displayed the students' end-of-course exams scores (only one exam per course), obtained through the school's score management platform. OFC stands for the online flipped classroom teaching model, while OLT is the online live teaching model.

Courses	Students	OFC	OLT	*Z*	*P*
Pharmacology	All physiology students 140 vs 118	73.00(56.88,82.13)	69.50(52.75,79.75)	-1.069	0.285
	High-achieving physiology students 38 vs 32	84.00(80.50,89.25)	80.50(73.50,86.00)	-2.150	0.032*
	Low-achieving physiology students 38 vs 32	46.00(29.75,60.75)	50.50(35.50,62.00)	-0.867	0.386
Pathology	All physiology students 140 vs 118	84.50(78.00,89.00)	83.50(75.00,88.00)	-1.050	0.294
	High-achieving physiology students 38 vs 32	90.00(86.75,92.25)	89.50(87.00,92.00)	-0.117	0.907
	Low-achieving physiology students 38 vs 32	70.25(60.38,79.50)	70.50(62.00,79.50)	-0.131	0.895
Diagnostics	All physiology students 140 vs 118	68.00(58.00,76.25)	65.25(57.00,73.81)	-1.195	0.232

High-achieving physiology students				
38 vs 32	79.75(73.50,84.25)	76.25(70.63,78.25)	-2.206	0.027*
Low-achieving physiology students				
38 vs 32	49.50(43.38,58.63)	55.00(46.75,60.00)	-1.122	0.262

*P<0.5, **P<0.01

Table 7. Comparison of NQROC learning data of high- and low-achieving students in OFC. We used the Mann-Whitney U test to compare the NQROC learning data of high- and low-achieving students, which partially illustrated the students' online autonomous learning input, to determine whether there are differences in NQROC learning situation between the high- and low-achieving students. The NQROC learning data comprised the video viewing overtime, number of messages which were sent to the discussion board and NQROC online quiz scores. The data came from the NQROC platform-i-Course. NQROC stands for national quality resource of open courses.

NQROC learning data	High-achieving physiology students (n=38)	Low-achieving physiology students (n=38)	*Z*	*P*
Online quiz scores	98.89(96.70,99.84)	94.40(77.30,97.88)	-4.240	<0.0001***
Number of messages sent to the discussion board	11(6,20)	6(-2,11)	-2.951	0.003**
Overtime of video viewing (min)	459 (115, 870)	311(-356, 772)	-1.330	0.184

***P*<0.01, ****P*<0.001