TEACHING INNOVATIONS

The effectiveness of formative assessment in pathophysiology education from students’ perspective: a questionnaire study

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Cong X, Zhang Y, Xu H, Liu LM, Zheng M, Xiang RL, Wang JY, Jia S, Cai JY, Liu C, Wu LL. The effectiveness of formative assessment in pathophysiology education from students’ perspective: a questionnaire study. Adv Physiol Educ 44: 726–733, 2020; doi:10.1152/advan.00067.2020.—Current interdisciplinary curricula have been developed for reforming medical education in China. Aims. To measure the improvements in learning and teaching brought by a multidisciplinary formative assessment (FA) system. Methods. A questionnaire survey was conducted to gather data on the reformed FA system before questionnaire collection. Moreover, both the formative and summative assessment scores of all the students from 2017 to 2019 had been enrolled for three consecutive years from 2017 to 2019. Their majors included clinical medicine, basic medical sciences, stomatology, preventive medicine, nursing, medical laboratory diagnosis, and biomedical English. All participants signed an informed consent document before questionnaire collection. Results. The reformed FA system was well received by the students. The students thought that the FA assessment not only allowed the provision of immediate feedback from students to further improve the teaching skills of lecturers, thereby providing an advantageous approach to more reliably evaluate levels of learning and teaching. An effective teaching assessment system is a critical piece of the puzzle in interdisciplinary medical training. To address challenges in undergraduate pathophysiology education, we have introduced case-based multiple-choice questions (MCQs) into the formative assessment for students majoring in clinical medicine and basic medical sciences beginning in 2012 and have begun to gradually combine multimethod formative assessment with traditional summative assessment beginning in 2016. This reform has achieved encouraging results and has served as both a driver and a real-time indicator of teaching. To gain insights into the new assessment system from the perspective of students, we surveyed the undergraduates who participated in the pathophysiology course. We hypothesized that the application of the formative assessment would contribute to the improvement of pathophysiology learning from multiple aspects and therefore be well received by students.

INTRODUCTION

Pathophysiology is an important discipline concerned with the study of the etiology and pathogenesis of human diseases, and it serves as a bridge between basic medical science and clinical practice (7). Learning pathophysiology requires logical thinking for the multiple integration, analysis, induction, and deduction of knowledge from basic medical courses (8). This requirement introduces challenges for lecturers, who have to improve student engagement and achievement, guide students to use logical thinking to analyze and solve clinical problems, and cultivate students with a strong ability for self-based learning and cooperation.

METHODS

Participants. All participants were third-year undergraduate medical students at Peking University Health Science Center (PKUHSC) who had been enrolled for three consecutive years from 2017 to 2019. Their majors included clinical medicine, basic medical sciences, stomatology, preventive medicine, nursing, medical laboratory diagnosis, and biomedical English. All participants signed an informed consent document before questionnaire collection. Moreover, both the formative and summative assessment scores of all the students from 2017 to 2019.
were collected, and the semesterly final scores of 235 students with similar majors, except clinical medicine and basic medical sciences, in 2014 served as indicators of performance before the formative assessment was incorporated.

**Design of the formative assessment.** The course of pathophysiology at PKUHSC is 36 credit hours, including 13 units during one semester. The formative assessment was elaborately designed step by step with an increasing number of required methods and increasing difficulty. For the students majoring in clinical medicine and basic medical sciences (classified as group 1) and the students majoring in other medical subjects (group 2), the reformed formative assessment consisted of case-based MCQs (see “case-based MCQs” items in Table 1), and it was completed by scanning QR codes generated from a new tool, SOJUMP (https:\/\!/www.wjx.cn\/). SOJUMP is a service provider engaged in online examinations, voting, and questionnaire platforms. After the MCQs are typed into the SOJUMP platform, a QR code is automatically generated. In 2017, to train the students in clinical reasoning rather than the ability to choose correct answers from given options, case study questions were introduced into the formative assessment for all students (see “case study questions” items in Table 1). To encourage the students to learn from each other, all the homework as well as the answers provided by lecturers were posted online so that the students could review them voluntarily. Beginning in 2018, 10 featured completed homework assignments of a total of 150 assignments were recommended by lecturers and teaching assistants for reading and comparison according to the following standards: 1) reasonable case; 2) clear description; 3) good question(s) with detailed explanation; 4) integration of multiple subjects; and 5) unique and novel insight.

Furthermore, we provided a means to further support the development of creativity, communication skills, and teamwork. The group-based, student-set MCQs or case study questions were administered to students majoring in clinical medicine and basic medical sciences (refer to “case-based MCQs or questions set by students” item in Table 1). Case-based MCQs were composed of one question based on a case and had five possible choices, including one correct answer and four incorrect answers (distractors). Case study questions were short-answer questions composed of a brief prompt that required a written answer varying in length from one to a few sentences. Students were allowed to work in three-person teams of their own choosing, and they could discuss and write questions themselves after class. The detailed explanation and/or analytical process for these questions were also provided by the students. At the very beginning of the class, the lecturers introduced the structure of the case-based MCQs and case study questions and instructed the students to write questions themselves, following a series of steps (preparing, drafting, revising, and editing). The standardized questions from the first five formative assessments that had been written by lecturers, including case-based MCQs and case study questions, were again presented to all the students as models. Finally, the students finished their own work.

The structure of the currently implemented multimethod assessment system for pathophysiology after a series of reforms is shown in Table 1. Each formative assessment quiz was performed by lecturers either at the beginning or at the end of classes every 6–8 credit hours.

**Questionnaire.** At the end of the course, students were asked to complete an anonymous questionnaire about their experiences with this reformed assessment system. The questionnaire consisted of 12 questions for students majoring in clinical medicine and basic medical sciences and 9 questions for other students; since the former group used student-set questions, these students were asked additional questions. Of the included questions, 11 or 8 were MCQs, and students were asked to rank each statement on a scale such as a scale from “strongly agree” to “strongly disagree.” One question was a ranking question to inquire about the most influential impacts on learning in the pathophysiology course. Additionally, open-ended questions were included to allow the students to comment on the formative assessment. The question clusters and related aspects in the survey are shown in Table 2.

**Pilot testing.** The questionnaire was pilot tested with 16 participants majoring in clinical medicine (8 men and 8 women). Participants were asked whether they had any difficulty in answering the questions and whether they found any of the questions to be confusing or upsetting or to contain obscure expressions. Furthermore, reliability and validity tests of the questionnaire were performed.

During pilot testing, none of the questions was problematic, confusing, or offensive. The questionnaire had high internal consistency (Cronbach’s alpha = 0.883 and ranged from 0.848 to 0.932). The Kaiser–Meyer–Olkin (KMO) test yielded a score of 0.681, and Bartlett’s test of sphericity yielded a P value < 0.001. Principal component analysis (PCA) supported a construct with two dimensions, which explained 81.42% of the variance. Therefore, the questionnaire was found to be a reliable and valid tool for scientific purposes.

**Data analysis.** The results were analyzed by SPSS 18.0 software (Chicago, IL). The reliability of the questionnaire was determined via analysis of its internal consistency using Cronbach’s alpha coefficient; the alpha coefficient should be above 0.8 to support reasonable internal consistency. To discover the underlying structure of the data, the KMO, Bartlett’s test of sphericity, and PCA were conducted. The descriptive statistics were calculated to evaluate demographic differences in the responses; these statistics are presented as both exact numbers and percentages. After the survey was closed, the open-ended student responses were reviewed and summarized. For the ranking question, the weighted average score was calculated as (Σ frequency × weight)/total responses. A higher score indicates a higher ranking.

The score data are presented as means ± SD. Statistical analysis was performed by one-way analysis of variance (ANOVA) among multiple subjects (classified as group 1 and the students majoring in other medical subjects. Group 2) unique and novel insight.

### Table 1. Items and scores of the assessment system

| Group 1 | Group 2 |
|---------|---------|
| **Content** | **Score** | **Times** | **Subtotal** | **Score** | **Times** | **Subtotal** |
| Formative assessment | 30 | | | Case-based MCQs | 6 | 3 | 18 |
| Case-based MCQs | 5 | 3 | 15 | Case study questions | 6 | 2 | 12 |
| Case study questions | 5 | 2 | 10 | | | |
| Case-based MCQs or questions set by students (3 persons/group) | 5 | 1 | 5 | | | |
| Summative assessment | | | | Final written examination | 70 | | 70 |
| Total | 100 | | | 100 | | |

*Group 1* includes the students majoring in clinical medicine and basic medical sciences. *Group 2* includes the students majoring in other medical subjects.
groups with GraphPad software (GraphPad Prism 6.01, San Diego, CA). Correlations were analyzed by Pearson’s coefficient correlation analysis. $P < 0.05$ was considered statistically significant.

RESULTS

Respondent profile. A total of 1,277 questionnaires (262 respondents in 2017, 570 in 2018, and 445 in 2019) were returned by 1,673 students (76.3% response rate). Among the students who returned questionnaires, 644 respondents were majoring in clinical medicine, 187 were majoring in basic medical sciences, 87 were majoring in stomatology, 102 were majoring in preventive medicine, 157 were majoring in nursing, 38 were majoring in medical laboratory diagnosis, and 62 were majoring in biomedical English. Of the students who returned questionnaires, 579 were male (45.3%) and 698 were female (54.7%).

Effectiveness of the assessment method. Initially, the effectiveness of the current assessment system for learning pathophysiology was surveyed. Four hundred and forty-one (34.5%) respondents thought that the combination of the formative assessment and summative assessment very effectively provided immediate feedback on their learning progress. Seven hundred and thirty-seven (57.7%) respondents agreed that the assessment system was effective, 52 (4.1%) were uncertain, and 47 (3.7%) reported that it was ineffective (Fig. 1A). Compared with the traditional one-time, end-of-semester examination, the combined formative and summative assessment system was thought to result in no significant increase in workload by 518 (40.6%) respondents, and 49 (3.9%) reported that it resulted in no additional burden at all. One hundred and sixty-nine (13.2%) respondents were unsure, 432 (33.8%) thought that the workload was somewhat increased, and only 109 (8.5%) felt that the new method significantly increased their workload (Fig. 1B). Furthermore, most respondents ($n = 1,209$; 94.7%) agreed that the course should continue to use the formative and summative assessment system, and only 68 (5.3%) disagreed (Fig. 1C).

Content and completion of the formative assessment. Next, the content of both the case-based MCQs and the case study questions used in the formative assessment was evaluated by students. Four hundred and twelve (32.3%) respondents reported that these questions dramatically helped them understand and apply the theories. The majority of the sample ($n = 759$; 59.4%) thought that these questions were somewhat helpful. Sixty-five (5.1%) were uncertain, and 41 (3.2%) reported that the questions were not helpful (Fig. 2A).

Beginning in 2014, the case-based MCQs were accessed by scanning QR codes generated from SOJUMP. When asked if this was an appropriate way to take the quiz, 359 (28.1%) respondents strongly agreed that it was suitable, 739 (57.9%) agreed, and the minority disagreed ($n = 91$; 7.1%) or were unsure ($n = 88$; 6.9%) (Fig. 2B). Regarding the responsiveness of lecturers after their review of students’ MCQ answers and scores, 806 (63.1%) respondents reported that the feedback was prompt with thorough explanations, 360 (28.2%) thought that the feedback was prompt but the explanations were too brief, and 111 (8.7%) reported that they did not receive feedback from lecturers (Fig. 2C).

After the completion of the case study test, the answers provided by lecturers and all the homework from students were posted online so that the students could compare and learn from...
while 132 (132/543 = 24.3%) somewhat agreed with it. A small proportion (70/543 = 12.9%) somewhat disagreed and only 9 (9/543 = 1.7%) strongly disagreed with this type of questions (Fig. 4A). Since the format involved a collaborative effort, 100 (100/543 = 18.4%) respondents reported that it significantly promoted communication and exchange of ideas with peers, 300 (300/543 = 55.2%) thought it was somewhat helpful, 55 (55/543 = 10.1%) were uncertain, 79 (79/543 = 14.6%) responded that the format helped to a limited degree, and 9 (9/543 = 1.7%) did not believe it helped at all (Fig. 4B). When asked about the preparation time necessary to search for and collect materials and discuss among group members before starting to write responses, the majority (314/543 = 57.8%) reported that they needed <5 h, 185 (185/543 = 34.1%) reported needing 5–10 h, 32 (32/543 = 5.9%) spent between 10 and 15 h, 4 (4/543 = 0.7%) needed 15–20 h, and only 8 (8/543 = 1.5%) required >20 h (Fig. 4C).

Impacts on pathophysiology learning. To determine the impacts of the current assessment system on learning in the pathophysiology course, the students were asked to choose their top three most preferred items. The eight items were organized according to three aspects that we hoped would be important to students in learning pathophysiology. The first aspect was to acquire knowledge through self-learning; the second was to train in multiple abilities, such as analysis, presentation, and communication; and the third was to cultivate lifelong learning attitudes, professional ethics, and social responsibility. Table 4 lists the ranking with scores for all the impacts according to data from the 1,277 respondents.

Comments and suggestions on the formative assessment. As a qualitative part of the study, the open-ended case study questions and student-set questions could be answered in depth to allow students to provide their unique and detailed responses. In the feedback on the case study questions, responses from the students were mostly positive and constructive. Their comments differed in their themes, which could be divided into two main aspects. First, regarding the significance of the case study questions, most respondents reported that these questions trained their analytical skills for clinical cases and prompted them to review and reflect after class. Second, many respondents referred to the online open, visible homework available after each quiz. They thought that by reviewing and comparing their own answers to the answers from the lecturers and their peers, they could see the areas for improvement more clearly, reflect

Table 3. Summary of the respondent distribution regarding the review of peers’ homework between 2017 and 2019

| Numbers | 2017, n (%) | 2018, n (%) | 2019, n (%) |
|---------|-------------|-------------|-------------|
| 0       | 91 (34.7%)  | 189 (33.2%) | 104 (23.4%) |
| 1–10    | 161 (61.5%) | 352 (61.8%) | 323 (72.6%) |
| 11–30   | 9 (3.4%)    | 27 (4.7%)   | 14 (3.1%)   |
| 31–60   | 0 (0.0%)    | 0 (0.0%)    | 3 (0.7%)    |
| >60     | 1 (0.4%)    | 2 (0.4%)    | 1 (0.2%)    |

Fig. 3. Attention to the answers reviewed by the students in 2017 (A) and 2018 and 2019 (B).
on their learning methods, learn to approach questions from different perspectives, and be more appropriate and precise with medical terminology in their writing. Additionally, the students provided many good suggestions. For example, they suggested that the lecturers should generate in-depth discussions about the cases and critique their homework in class, comment on common mistakes, and highlight areas for improvement. The students also suggested that the explanations should cover more depth and breadth in each case rather than being limited to only addressing the questions.

The students majoring in clinical medicine and basic medical sciences also commented on the positive motivation from the student-set case-based questions, which represented a new format of the formative assessment. Their feedback mainly covered three aspects. First, the majority believed that this activity helped them better understand concepts and theories, exercise their logical reasoning, and assimilate lecture content. By researching past cases, the students attained early exposure to clinical training, which in turn reinforced their conceptual learning and problem-solving skills. Second, the students found that the teamwork they participated in helped with their interpersonal skills. Third, many respondents reported that this assessment improved their command of the written language. In addition, some respondents expressed the challenges they faced while writing their case study questions. For example, the students had limited access to past cases and wished that the lecturers could have provided help in this regard. They also needed templates from the lecturers that they could use for their own writing. Moreover, the students proposed that the homework could be to rewrite original case reports that were provided by lecturers or write questions based on these cases. Finally, as some respondents made up the cases entirely by themselves, the accuracy and reliability of the writing might have been questionable. In this case, they felt very confused and needed help from the lecturers.

**Effects of the formative assessment on course scores.** To evaluate whether the implementation of the formative assessment affected course scores, we collected final scores from all 1,673 students from 2017 to 2019. Compared with the scores of 235 students who did not complete the formative assessment in 2014, the semesterly final scores in 2017, 2018, and 2019 increased (Fig. 5A). The distribution showed that the percentages of semesterly final scores that were above 90 or ranged from 80 to 90 were higher in 2017, 2018, and 2019 than in 2014, whereas the percentages of scores ranging from 70 to 79 and from 60 to 69 were lower after the formative assessment was incorporated (Table 5). Furthermore, although the formative and summative scores were not obviously changed in 2017, 2018, and 2019, the correlation analysis showed significant positive relationships between both assessment scores, as well as an increasing Pearson’s correlation coefficient year over year (Fig. 5, B–E).

**DISCUSSION**

In this study, undergraduate medical students completed a questionnaire that asked about their perceptions of a reformed assessment system in the teaching of pathophysiology. The results showed that the combined formative and summative assessments were highly received by respondents and this comprehensive system empowered the students to learn more actively and efficiently.

Traditional final examinations provided only one opportunity for the evaluation of student learning outcomes. This approach neither provided a fair assessment of learning outcomes nor promoted students’ engagement in class (4). As a result, many students underperformed somewhat during the first half of the semester and overstrained themselves in the second half, sometimes even cramming toward the end of each semester. The formative assessment could change their study habits, encouraging them to learn more efficiently in class, reflect and summarize after class, and become more self-motivated, thus manifesting the philosophy of “student-centered, self-motivated” teaching. The formative assessment could also allow the lecturer to adjust his/
her teaching style and methods in a timely manner according to the students’ formative assessment results (1, 6, 10).

Because of the characteristics of pathophysiology, more emphasis should be placed on development of students’ analytical and problem-solving skills in teaching (8, 11). In recent years, we first performed a formative assessment as part of the curriculum for students majoring in clinical medicine and basic medical sciences; we received positive responses and then applied it to medical students from all majors. The questionnaire analysis showed that the formative assessment was well accepted by all students, who thought it helped them better understand their progress in self-study. The students were more engaged, as they had enthusiasm in class and were encouraged to summarize and review the learned knowledge after class. At the same time, the formative assessment did not increase perceived workload and was therefore an encouraging reform that should be continued and promoted.

In this step-by-step reform, unwavering efforts have been made to explore and improve the content of the formative assessment. For undergraduate medical students who may have limited clinical experience or observation of actual patients, early studies have suggested that case-based questions not only...

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**Table 5. Distribution of students’ course scores in 2014, 2017, 2018, and 2019**

| Scores | 2014, n (%) | 2017, n (%) | 2018, n (%) | 2019, n (%) |
|--------|-------------|-------------|-------------|-------------|
| >90    | 40 (17.0%)  | 118 (36.4%) | 132 (21.0%) | 234 (32.5%) |
| 80–90  | 75 (31.9%)  | 142 (43.8%) | 269 (42.8%) | 308 (42.7%) |
| 70–79  | 53 (22.6%)  | 45 (13.9%)  | 140 (22.3%) | 93 (12.9%)  |
| 60–69  | 63 (26.8%)  | 15 (4.6%)   | 64 (10.2%)  | 61 (8.5%)   |
| <60    | 4 (1.7%)    | 4 (1.2%)    | 23 (3.7%)   | 25 (3.4%)   |

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Fig. 5. Effects of the formative assessment on course scores. A: the semesterly final scores of the students in 2014 (without formative assessment) and 2017–2019 (with formative assessment). The score data are presented as means ± SD. Statistical analysis was performed by 1-way analysis of variance (ANOVA) among multiple groups. B: the formative and summative assessment scores of the students between 2017 and 2019. C–E: the relationship between the formative and summative assessment scores in 2017 (C), 2018 (D), and 2019 (E). Correlations were analyzed by Pearson’s coefficient correlation analysis. Solid lines are fitted straight lines, and dashed lines are error bars.
bring out students’ interests in learning but also cultivate students’ analytical skills and abilities to solve clinical cases (2, 3, 11). In 2012, we began to adopt a formative assessment for students majoring in clinical medicine and basic medical sciences. To cultivate the students’ analytical skills and ability to solve clinical cases, we introduced some case-based MCQs into both formative and summative assessments. After satisfactory results were found, the formative assessment has been entirely made up of case-based MCQs for students from all majors since 2016. Their semesterly final scores in 2016 did not decrease despite the increased difficulty; instead, fewer students scored in the ranges of 60–69 and 70–79, and more students scored in the range of 80–89 (13). In 2017, case study questions were introduced into the formative assessment for all students. The majority of students agreed that the introduction of these questions helped with their understanding and application of concepts to varying degrees and reminded them to summarize and periodically review their learning. After finishing their own case study homework, many students expressed that comparing their own answers with those of their lecturers and peers helped them broaden their views and learn to approach questions from other perspectives, which helped them better understand the significance of pathophysiology. Furthermore, the group-based, student-set, case-based MCQs or case study questions were written by students themselves. Making the students the question authors increased their engagement considerably and brought out their creativity. To write a good case-based question, the students needed to have a clear understanding of the medical condition, connect concepts, and apply them across disciplines. The survey showed that many students enjoyed this model to varying degrees and thought that the writing of case-based questions helped them better understand the key concepts through an emphasis on the signs and symptoms of the disease. These activities integrated basic medical concepts and clinical practices and encouraged communication and collaboration without excessively increasing the workload. In addition, the well-designed MCQs and case study questions could be added to the department’s question bank for future use in examinations for future students of the pathophysiology course. Students who wrote these well-designed MCQs saw the addition of their questions to the question bank as a form of recognition and appreciation. Questions that were not good enough to be added to the question bank were saved to be modified by lecturers and presented with comments online or in class as examples for students in the next semester.

A comprehensive assessment system can definitely affect students’ preferences for learning in a course (5, 12). Of all the favorable impacts, the top three in the students’ view were the review and consolidation of the fundamental concepts, training in analytical skills, and a holistic understanding of basic medicine and clinical medicine; these impacts were experienced because of the quantity of case-based questions the students practiced and their requirement to organize and summarize their knowledge. In addition, the students also reported that they became more self-motivated and better at collaborative work. Thus, the reformed assessment system contributed to students’ holistic development. The changes and improvements in their studying habits benefited the students not only in their pathophysiology learning but also in their future endeavors in other subjects.

From the survey results, it should be noted that the implementation of the formative assessment introduced many challenges for the lecturers. First, as the assessment content became more innovative, the coverage became more extensive; in addition, when the format was digitized, more was expected from the lecturers to cope with the changes in terms of knowledge, clinical experience, and computer skills. Differences in students’ thinking introduced information beyond that in the syllabus, which required deeper and broader knowledge from the lecturers. For example, much guidance was needed in the student-set, case-based questions, as many students obtained their clinical cases online, which were poorly documented. In some cases, the students designed their cases by themselves and were unsure about coherence and accuracy. The lecturers therefore not only needed to have a good grasp of the pathophysiology they were teaching but also were advised to invite clinicians to the classroom and take students to the bedside when possible. Additionally, the lecturers needed to receive technical training on software and equipment amid education reform in the information age. Second, as the informative assessment incorporated homework such as case study questions and student-set questions, the lecturers had more work to grade, and their workload was increased considerably. In this situation, some students still wished the lecturers would have given them more remarks and suggestions on their homework, which would inevitably have taken even more time. To address these issues, clear marking schemes could be made available to students in the future. Alternatively, lecturers could select and remark on some noteworthy works that may benefit more students or take advantage of the online platform to provide videos related to the cases for the students’ reference. Third, although new teaching and assessment methods have emerged in recent years, the methods need to be recognized and improved by students before they can help the students in their learning. Thus, the lecturers should not limit themselves to lecturing and should also make efforts to interact more with the students, assessing their suggestions and feedback. For example, some students complained that the lecturers marked their case-based MCQs briefly but only commented briefly or even provided no comment. We should respond accordingly and provide comments with each correct and incorrect answer either online or in class, making the teaching more efficient. The survey also revealed that lecturers should instill values and professionalism in the students so that students will have a better understanding of the professional and social responsibilities the medical profession entails.

Finally, we quantitatively evaluated the impact of the formative assessment on final performance. The results showed increases in the semesterly final scores in 2017 and 2019 compared with the scores of students who had not completed the formative assessment in 2014. More importantly, the summative assessment scores were positively related to the formative assessment scores, which indicated that students who have performed well throughout the learning process would be much more likely to obtain better scores in the final written examination. This improvement might be closely associated with improved self-motivated learning attitudes and extensive abilities inspired and trained by the formative assessment.

Limitations. Our study has several limitations. First, we have focused on and analyzed students’ scores in the pathophysiology course, whereas this is no indication that their scores in other
courses being taken concurrently did not also improve. Hence, the possibility of a cohort effect might be a limitation. Another important thing is that the survey lacked follow-up investigations on issues such as whether the students who obtained higher scores in the formative assessment perform better than others after beginning clinical practice, the impacts of case-based question training on students’ clinical practice, and their updated suggestions regarding the teaching of pathophysiology. Second, although the questionnaires in this study provided a practical tool for collecting data from a large sample, another limitation is that the survey was anonymous and voluntary and the results represented a snapshot of all the student experiences. Besides, although the survey response rate of 76.3% is excellent, the lack of participation by nearly 1/4 of the students does introduce a “selection bias” that should be acknowledged as a limitation. Finally, not inviting clinicians to review the case-based questions is also a potential limitation. These issues should be considered and addressed in future studies.

Conclusions. The implementation of the formative assessment was well received by the students because of its effectiveness, content, and impacts on learning outcomes. The assessment benefited the students and encouraged the lecturers to improve their teaching. In the future, more possibilities to improve the formative assessment system will be explored to advance our teaching of pathophysiology to the next level.

GRANTS

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DISCLOSURES

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

AUTHOR CONTRIBUTIONS

L.-L.W. conceived and designed research; Y.Z., H.X., L.-M.L., M.Z., R.-L. X. and J.-Y.W. performed experiments; X.C., Y.Z., S.J., and C.L. analyzed data; X.C. prepared figures; X.C. drafted manuscript; J.-Y.C., C.L., and L.-L.W. conceived and designed research; Y.Z., H.X., L.-M.L., M.Z., R.-L. X. and C.L. performed experiments; X.C., Y.Z., S.J., and C.L. analyzed data; X.C. edited and revised manuscript; X.C., Y.Z., H.X., L.-M.L., M.Z., R.-L.X., J.-Y.W., S.J., J.-Y.C., C.L., and L.-L.W. approved final version of manuscript.

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