Received: 6 November 2019 | Revised: 21 April 2020 | Accepted: 9 February 2021

DOI: 10.1002/bmb.21496

ARTICLE

Biochemistry and Molecular Biology Education WILEY

A mobile technology-based cooperative learning platform for undergraduate biology courses in common college classrooms

Chun Zhou[1] | **Matthew Lewis**[2]

[1]Department of Natural Sciences, School of Health and Natural Sciences, Mercy College, Dobbs Ferry, New York

[2]Center for Teaching and Learning, Mercy College, Dobbs Ferry, New York

Correspondence
Chun Zhou, Department of Natural Sciences, Mercy College, 555 Broadway, Dobbs Ferry, NY 10522.
Email: czhou1@mercy.edu

Present address
Matthew Lewis, CUNY School of Professional Studies, New York, USA

Funding information
Mercy College, Grant/Award Number: Teaching Innovation Microgrant

Abstract

As a high-impact educational practice, cooperative learning uses a structured group study to promote students' active learning. Currently, it lacks economical yet effective tools to facilitate the interactive nature of structured cooperative learning in regular classrooms. Here, we have established a mobile technology-based cooperative learning (MBCL) platform that comprises the 2018 iPad, Apple Pencil, LiveBoard, Google Forms, and Google Drive. We tested the MBCL platform in multiple undergraduate biology courses. During semester-long MBCL studies, the students engaged in cooperative learning to discuss a real-life issue or chapter-based contents. With the MBCL platform, the students' group study processes were shown on shared, visible electronic whiteboards that were updated in real-time, generating visible thinking and instant, interactive communication. The instructor was able to guide the students promptly to conduct knowledge integration and knowledge synthesis using tables and diagrams. The deep learning outcome was evident in the examples and quantitative analyses of students' whiteboard study results and team presentations. Thus, integrating innovative mobile technologies into high-impact teaching practices, exemplified by the MBCL platform, promotes deep learning in higher education.

KEYWORDS

biology, cooperative learning, deep learning, general biology, genetics, immunology, iPad, learning platform, microbiology, mobile technology

1 | INTRODUCTION

Group studies are proven to promote students' active learning, knowledge application, and academic performance in science, technology, engineering, and mathematics (STEM) courses.[1–3] Recognized as one of the high-impact practices by the Association of American Colleges and Universities, collaborative assignments and projects are often used in group studies.[4] In fact, small group studies have become a well-accepted teaching pedagogy in higher education, including medical schools.[5]

Among group study approaches, cooperative learning refers to the practice in which students form small study groups or teams to complete structured assignments toward a common learning goal through cooperation.[6–8] Cooperative learning has the following features: positive interdependence, face-to-face promotive interaction, individual and group accountability, interpersonal and small-group skills, and group processing.[9] This high-impact practice is related to social interdependence theory.[10] Positive interdependence can be achieved by structured group study. In such structured studies, the instructor designs the learning tasks that can be divided among team members, and students take different roles, such as facilitator, recorder, and reporter.[11] Face-to-face promotive interaction and discussion are deemed key to stimulating students' cognitive restructuring to infer and transfer ideas for deep learning; the latter can result in conceptual understanding, knowledge integration, and knowledge synthesis.[3,12] Furthermore, the active, structured cooperation among group members is key to successful cooperative learning, which depends on the instructor's design of the team tasks and effective structuring and administration of group studies.[13–15]

Currently, extensive studies have validated the positive impact of cooperative learning on developing students' reading, writing, presenting, and mathematical problem-solving skills.[1,16] However, the tools that can help instructors conduct and guide in-class cooperative learning are less developed. For example, specific high-tech group study classrooms have been designed to promote active learning. However, these high-tech classrooms require significant investment in fixed classroom equipment such as computers, wall-mounted computer screens, circle tables, and specialized software.[17] The regular teaching classrooms in most universities and colleges only have movable or fixed chairs and desks, a podium with a computer, and a large projection screen. In our previous practice of group studies in those standard classrooms, we found that it lacked a tool to facilitate the instructor's management of the in-class group study and timely communication between the instructor and students to promote deep learning.

Mobile technologies have been used to assist classroom learning and group work.[18–20] The iPad is a popular mobile technology utilized in classrooms, together with laptops.[21] The typical use of iPads in classwork includes taking notes, searching on the Internet, reading lecture slides, watching videos, and conducting virtual meetings.[22,23] Less developed in using iPads in higher education, however, is how to integrate the iPad technology for structured, innovative pedagogical methods to support the teaching process and curricula.[24]

In the present study, we set out to address the following two research questions. What novel teaching tools can help instructors conduct and guide cooperative learning in typical classrooms toward deep learning? How can the iPad mobile technology be utilized to promote deep learning in structured group studies? We hypothesized that by integrating the Apple Pencil and Apple Pencil-compatible iPad into cooperative learning, students' study processes could become visible to the instructor, and real-time, dynamic interactions between the instructor and students could be achieved in regular classrooms. We thought to test whether such a strategy can facilitate the realization of deep learning, especially knowledge integration and knowledge synthesis.

To this end, we have developed the Mobile Technology-Based Cooperative Learning (MBCL) platform and tested it in a set of undergraduate biology courses, including Microbiology Lecture, Genetics, Immunology, and General Biology I Lecture. The present study establishes a proof of principle that the MBCL platform can facilitate structured, dynamic cooperative learning in ordinary college classrooms, generate valuable teaching advantages such as visible thinking, and promote deep learning outcomes in knowledge integration and synthesis.

2 | METHODS

2.1 | Ethics statement

The Mercy College Institutional Review Board approved this research project (Project #: 18–59). The questionnaire was completed anonymously and voluntarily by the students in the Microbiology Lecture class, Genetics class, and Immunology class. To protect students' confidentiality, student volunteers conducted and collected the survey after the instructor had exited the classrooms. The consent for using students' teamwork results for research and publications has been obtained from all the students who participated in the present study.

2.2 | Instructional setting

We conducted the MBCL studies at Mercy College, a coeducational New York City area college with four campuses: the Dobbs Ferry, Bronx, Manhattan, and Yorktown Heights campuses. Mercy College is mainly an undergraduate teaching college with specific graduate and certificate programs. For MBCL activities, the Microbiology Lecture class and Genetics class were administered in the fall semester of 2018, and the Immunology class was conducted in the spring semester of 2019. There was a total of 48 students in the three classes. We did not consider a student who stopped attending the Genetics class due to personal issues. The MBCL studies were graded as a part of a student's final grade. After all the MBCL studies, an oral team presentation was conducted using PPT slides in which each slide was labeled with the student name who made that slide. Each student received an individual grade for their PPT slides and performance during the team oral presentation. In the fall semester of 2019, we conducted a control experiment of MBCL in another Genetics class of 15 students and a General Biology I Lecture class of 30 students, respectively. The class information of the present study is summarized in Table S1. Among those biology courses, the Genetics course has both lectures and labs while the rest courses are lecture classes.

2.3 | Group assignment

To assign the students of each class into three to four groups, we used the Blackboard learning management system (LMS). Each group has three to five students. The Blackboard LMS is referred to as Blackboard in the present study. The group size was based on our previous experience that small groups promote students' engagement and effective interaction. To benefit students at all academic levels and support students to learn from peers equally, we chose to divide students semi-randomly according to their scores of the grade point average (GPA) and allocated students of similar GPA levels to each group. As a result, each study team had a similar number of high, medium, and low GPA students. The assigned groups were kept the same over a semester to facilitate cooperation among team members.

2.4 | Role assignment

The students took turns to assume the following team roles. The facilitator was responsible for assigning subtasks, encouraging positive discussion, and timely completion. The recorder took notes and used the Apple Pencil and iPad to record the study results. The reporter presented team results to the class and answered the questions asked by other teams and the instructor. For each MBCL study session, a team had one facilitator, one or two recorders, and one or two reporters. The team roles were rotated among the team members during a semester for an equal opportunity to learning different team skills.

2.5 | Technology used

The 2018 iPads and Apple Pencils were purchased from Apple using a Teaching Innovation Microgrant awarded by Mercy College. The instructor was provided with a set of the iPad and Apple Pencil. Each student group used an iPad and Apple Pencil, and a total of four sets were shared among classes. The application LiveBoard was free at the time the present study was conducted. It was downloaded from the Apple Store and used after registration. We also accessed LiveBoard freely online at http://liveboard.online. Google Forms and Google Drive were free to use. Mercy College provides Blackboard to its students and instructors.

2.6 | Bioinformatics databases

Both the GenBank database and Online Mendelian Inheritance in Man (OMIM) database were accessed online at https://www.ncbi.nlm.nih.gov/ using the database selecting menu. The Universal Protein Resource (UniProt) database was used online at https://www.uniprot.org/.

2.7 | Student data collection and analysis

The same questionnaire was conducted after all the MBCL studies had been completed. The survey consisted of 16 questions that use the ratings based on the 5-point Likert scale. It includes Strongly Disagree (1 point), Disagree (2 points), Undecided/Neutral (3 points), Agree (4 points), and Strongly Agree (5 points). We attached a couple of yes or no questions to the survey on whether the students had previous experiences with in-class group study and using an iPad in group studies. The data from the three courses were analyzed utilizing Excel. After each in-class MBCL study, the completed electronic whiteboards of teamwork results were saved in the instructor's Google Drive account and later analyzed. On Blackboard, peer evaluation was conducted using Google Forms. The peer evaluation data were collected automatically in the instructor's Goggle Drive account.

In the fall semester of 2019, only two cooperative learning activities were conducted using two class times to compare the traditional method and the MBCL method in the General Biology I class and the Genetics class, respectively. For this comparison experiment, students' teamwork results were collected for analysis.

2.8 | Statistical analysis

The QuickCalcs online application of GraphPad (http://www.graphpad.com/quickcalcs) was used to analyze

2×2 contingency tables to yield two-tailed P values by Fisher's exact test. The t-test was conducted using EXCEL.

3 | RESULTS

3.1 | MBCL platform and its functional components

To facilitate cooperative learning, we chose to utilize cutting-edge mobile technologies linked to the 2018 iPad and the Apple Pencil, which allow knowledge integration and synthesis via constructing tables and diagrams, just like doing so on a piece of paper but with the new ability to revise electronically at ease. The 2018 iPad and Apple Pencil, used during the present study, can be replaced with newer iPads and Apple Pencils.

To help instructors guide students' study through real-time feedback, we identified a free iPad application called LiveBoard that allows the sharing of hand-writing illustrations instantly in the classroom. With LiveBoard, student groups can record their study results in the form of electronic whiteboards; multiple electronic whiteboards can be shown on the classroom projection screen and updated lively. If needed, the instructor can revise students' whiteboards directly using the instructor's iPad to show students how to improve their study directly on their work. Together, the iPad, Apple Pencil, LiveBoard, and classroom projection screen form the core components of the MBCL teaching platform. These core components provide a real-time information exchange of students' group study progress between the students and instructor. It is equally important that these core mobile components, independent of classroom settings, allow the MBCL platform to be carried from one classroom to another, permitting the sharing of a set of hardware—iPads and Apple Pencils—among instructors for their use in different classes.

Finally, we identified other mobile software that could work together with the core MBCL components to facilitate in-class MBCL activities. First, we used Blackboard to manage MBCL student groups, but other LMS software, such as Canvas, can do the same. The use of Blackboard integrated the MBCL activities into the instructor's course management system. Second, we employed Google Forms for conducting a short online survey with which every student could give a score to each of the teammates based on individual contribution to the group study (Figure S1). The adoption of peer evaluation was based on previous studies to reduce the free-riding behavior, which takes place when an individual contributes so little to the teamwork, leaving the task for others to complete.[25] We then embedded this Google Forms survey into the Blackboard course sites for students to use. The use of Google Forms allowed the peer evaluation results to be saved automatically in the instructor's Google Drive account. In the peer evaluation questionnaire, students were able to explain their reasoning on any unusually high or low scores that were given to their team member(s). Third, Google Drive was used to store group study results. The MBCL platform is illustrated in Figure 1a. While we used the iPad and Apple Pencil, other tablets and digital pens based on the Android and Windows operating systems can also be used in the MBCL platform as the software used in the present study can run on these operating systems. Similarly, instead of LiveBoard, other applications can be used to generate online instant sharing whiteboards in the MBCL platform. Those alternative options can make the MBCL platform more flexible to different instructional users.

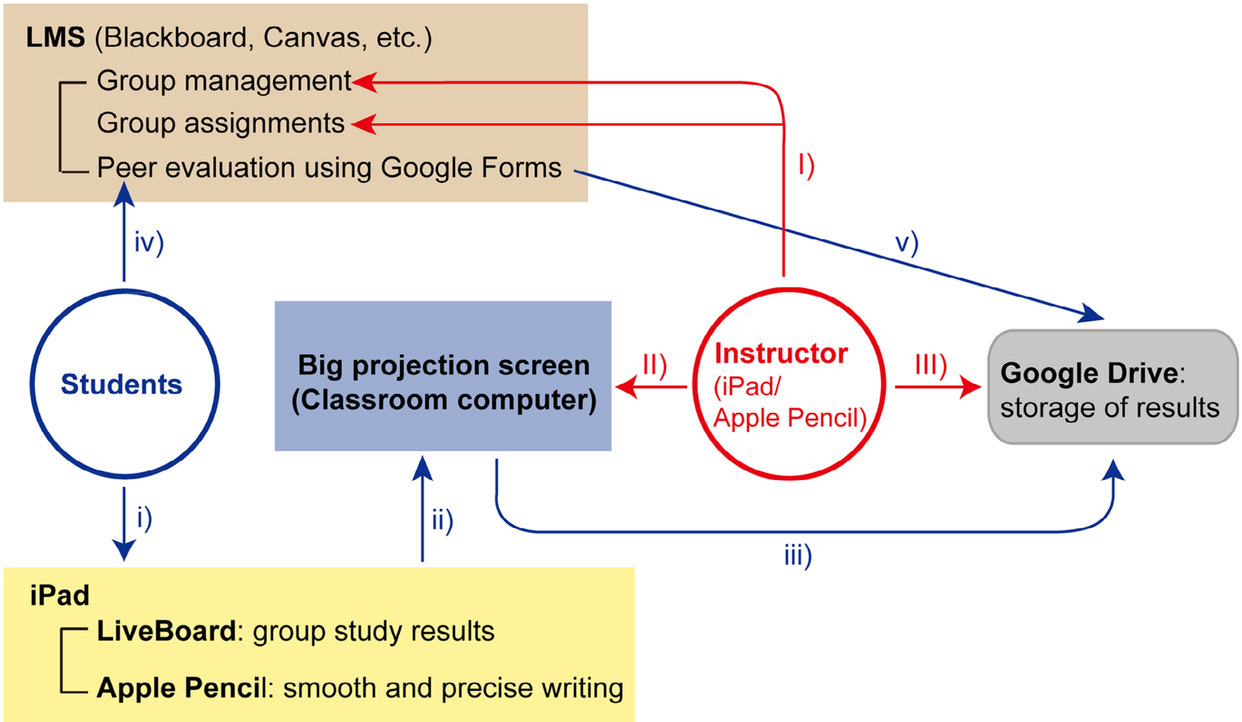
3.2 | MBCL promotes deep learning in thematic studies

For the two courses in the fall semester of 2018, we designed a set of MBCL study sessions that were unified under a theme. The topic of the MBCL studies in the Genetics class was the pathogenic mechanisms of a selected genetic disease from gene to protein. In the Microbiology Lecture class, the topic was the pathogenic mechanisms of a medically important bacterium. For each class, there were four MBCL study sessions (Figure 1b). The fourth session was a focused study (Figure S2). In this session of almost 3 h, the students were challenged with a real-life issue and worked on structured assignments to identify, integrate, and synthesize knowledge.

In the focused study of both classes, the students were able to complete the assigned tasks and conduct active learning. Here we show the study results of a student group in the Microbiology Lecture class to demonstrate how the students were able to complete knowledge identification, integration, and synthesis using the MBCL platform.

Figure 2 shows the whiteboard results of a team studying *Salmonella enterica* serovar Typhi (*S*. Typhi). On the first page of their whiteboard (Figure 2, left upper panel), the students summarized the main features of *Salmonella* and listed the major virulent factors in three categories: structural factors, enzymes, and endotoxins. On the second page of their whiteboard, they listed the main symptoms of typhoid fever (Figure 2, right upper panel). The first two pages met

(a)



(b)

1	2	3	4	5
1) MBCL introduction 2) Apple Pencil training 3) Liveboard training 4) MBCL demonstration	Explore genetic diseases Explore medically important bacteria	Select a genetic disease to study Select a medically important bacterium to study	**Focused study**	Team presentation and critique
50 min	50 min	50 min	170 min	170 min

FIGURE 1 MBCL platform and studies. (a) Principal components and workflow of the MBCL platform. In MBCL studies, the student-generated information flows in blue. The instructor carries out the tasks indicated in red. (b) The semester-long MBCL studies consisted of four sessions, from left to right. Each of the first three sessions used 50 min at the end of a regular lecture class. The fourth session was a focused study that took an entire lecture class. After all the MBCL studies, an additional session (session 5, in red) was conducted for the students to give an oral team presentation using PowerPoint slides; the presentation was critiqued by the instructor and students in the format of questions and answers. Min, minutes [Color figure can be viewed at wileyonlinelibrary.com]

the requirements of the assigned tasks of the focused study (Figure S2b).

During the group discussion (Task 3), the instructor monitored the projection screen for the live progress of the group study and encouraged this team to explore further on the pathogenic mechanism related to the cytidine monophosphate (CMP)-*N*-acetylneuraminic acid hydroxylase (CMAH). When the group discussion was completed, this team had generated the third page of their whiteboard (Figure 2, left lower panel). The instructor later discussed the role of CMAH in the pathogenesis of *S*. Typhi to the class. Directly on the students' whiteboard, the instructor added and revised the relevant information (Figure 2, right lower panel). The students were able to use the MBCL platform to conduct knowledge identification, integration, and synthesis. The instructor's timely suggestion helped the students establish the molecular mechanism by which typhoid fever is a human-specific disease. Finally, the instructor worked directly on students' study results to show how their work could be improved (Table S2).[26–29]

3.3 | MBCL used as a regular in-class activity in the Immunology course

In the Microbiology Lecture and Genetics classes, we used the MBCL platform for limited numbers of in-class cooperative learning to address a core study theme. However, the MBCL platform can also be utilized for

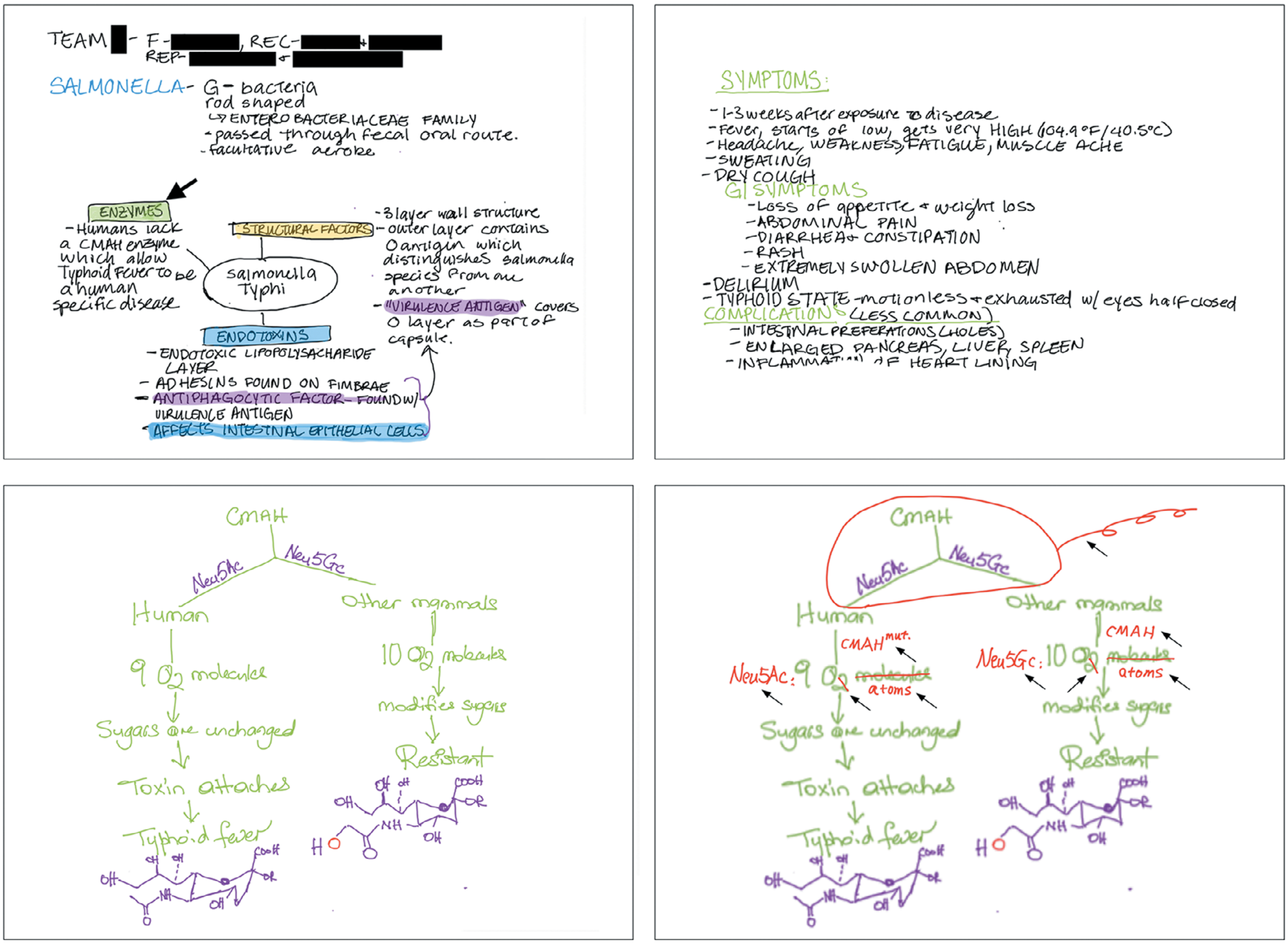
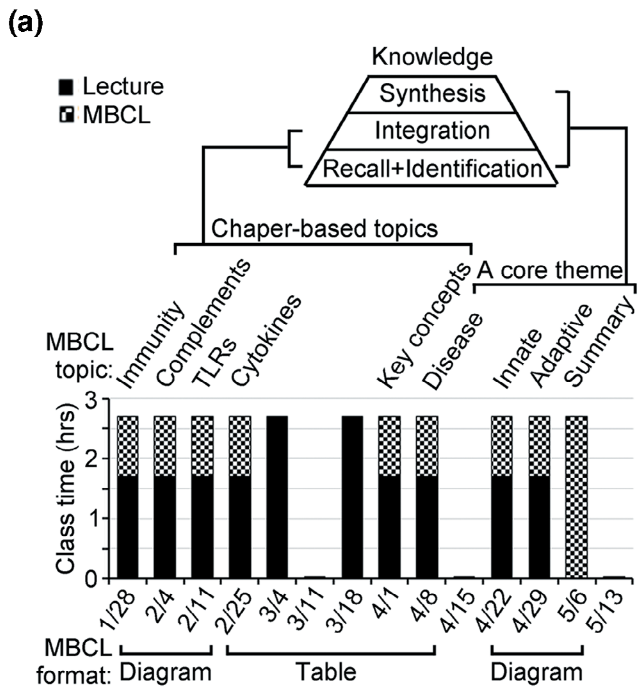


FIGURE 2 Knowledge integration and synthesis in MBCL. The whiteboard results of a student team in the Microbiology-Lecture class are shown as an example. The first page of the whiteboard in the left upper panel contains the student names (F: Facilitator, REC: Recorders, REP: Reporters) covered by the black rectangles. The right upper panel shows the second page of the whiteboard. The left lower panel contains the third page of the whiteboard. The right lower panel is the instructor's revision of the third page of the students' whiteboard, in which the black arrows indicate the places of the revision, including deleted and added words in red [Color figure can be viewed at wileyonlinelibrary.com]

cooperative learning activities that are not under a single theme but focused on various lecture-based topics. This strategy may help scaffold the deep learning skills through generating tables and diagrams over a semester. We chose to test this possibility by using the MBCL platform in the Immunology course in the spring semester of 2019.

As shown in Figure 3a, we conducted individual MBCL studies in five lecture classes that focused on chapter-based key concepts (Jan. 28, Feb. 4, Feb. 11, Feb. 25, and Apr. 1). Also, we conducted four MBCL studies (Apr. 8, Apr. 22, Apr. 29, and May 6) under a core theme to investigate a real-life issue, a selected immunological disease, so that the students could identify and integrate the taught and untaught knowledge and synthesize the pathogenic molecular mechanisms. Creating tables and diagrams served as the means for the students to think critically and to integrate and synthesize knowledge. The MBCL activities on chapter-based topics are more related to knowledge recall, identification, and integration. The MBCL activities under a core theme focused more on knowledge integration and synthesis that are considered as higher-order thinking skills (Figure 3a).

To analyze students' whiteboard MBCL study results quantitatively, we generated a rubric for grading the tables and diagrams. As shown in Figure 3b, students' study results were differentiated based on the following criteria: (1) whether the table or diagram was completed, and (2) the number of errors in the molecular concepts or mechanisms required to complete the MBCL assignments. Figure 3c,d shows two examples of the tables generated by an MBCL group. For the first MBCL study using tables, this group was able to generate the table of the assigned cytokines. However, the functions of certain



(b)

Score	Criteria	
1	Table generated with 3 or more places of uncompleted items	Diagrams partially completed
2	Table generated with less than 3 places of uncompleted items	Diagrams completed with 5 or more inaccurate or wrong molecular concepts
3	Table comleted with 4 or more errors	Diagrams completed with 3 or 4 inaccurate or wrong molecular concepts
4	Table completed with 3 or less errors	Diagrams completed with 1 or 2 inaccurate or wrong molecular concepts
5	Table completed with no apparent errors	Diagrams completed with no apparent inaccurate or wrong molecular concepts

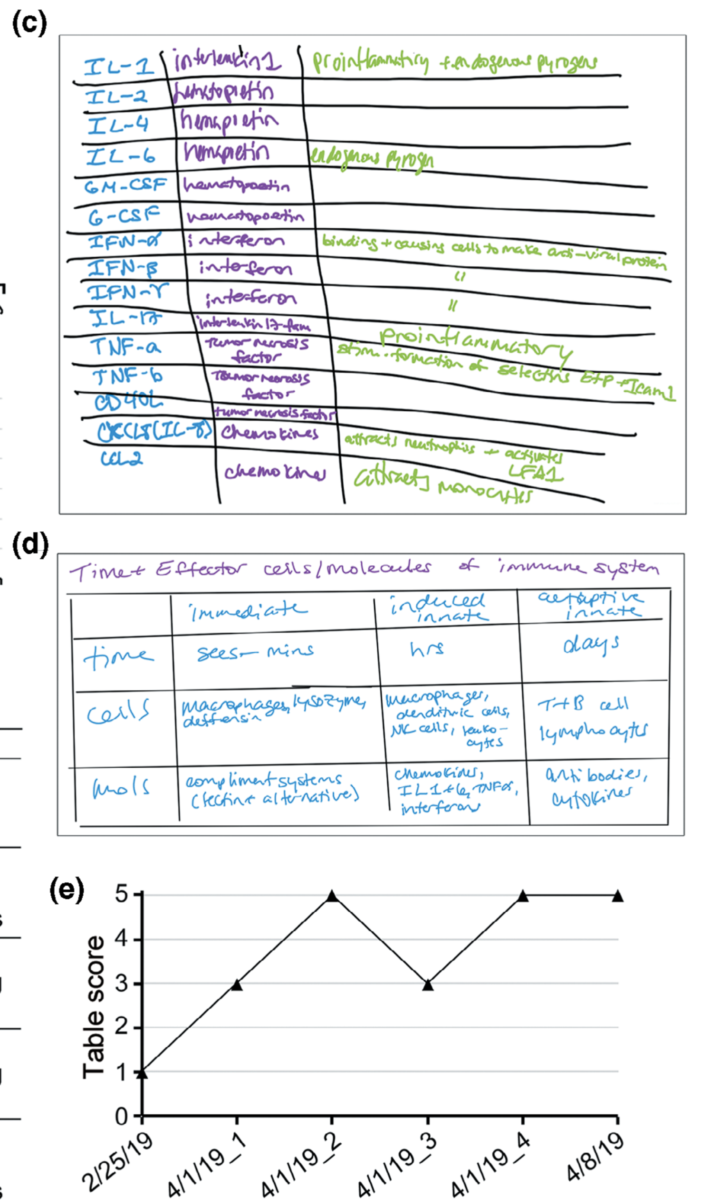


FIGURE 3 Regular in-class MBCL activities in the Immunology class. (a) The MBCL platform was used to conduct cooperative learning activities as a regular component of the classes. The first five MBCL activities addressed the chapter-based topics of immunity, complements, toll-like receptors (TLRs), cytokines, and other key concepts and mechanisms taught in class. The remaining four MBCL studies were under a core theme to discuss the pathogenic mechanisms of a student-selected immunological disease. Mar. 11, Apr. 15, and May 13 were used to conduct three lecture exams. The study skills learned in those activities were categorized into three levels from basic to complex: knowledge recall and identification, knowledge integration, and knowledge synthesis. (b) A rubric was used to grade students' whiteboard study results. The left column of criteria is for table results, and the right is for diagram results. The score range was from 1 point to five points (low to high). (c–e) Analysis of the tables generated by an MBCL group. Two table examples are given as (c) (Feb. 25) and (d) (Apr. 1). The scores of the six tables generated on Feb. 25 (one table), Apr. 1 (four tables), and Apr. 8 (one table) are presented in (e). Hrs, hours [Color figure can be viewed at wileyonlinelibrary.com]

cytokines were missing (Figure 3c). Compared to the table in Figure 3c, which was graded for one point due to three or more places of uncompleted items, the table that was generated by this group toward the end of the semester (Figure 3d) did not have apparent errors or missing items and therefore was given five points. In fact, Figure 3e indicates an overall increase in table grades. Thus, with multiple MBCL activities in generating tables, the students gained knowledge recall, identification, and integration skills to assist their study in immunology.

Compared to tables, diagrams were used to illustrate logical thinking steps and complex molecular mechanisms. The diagram examples in Figure 4a–c come from three MBCL activities of the same student group on

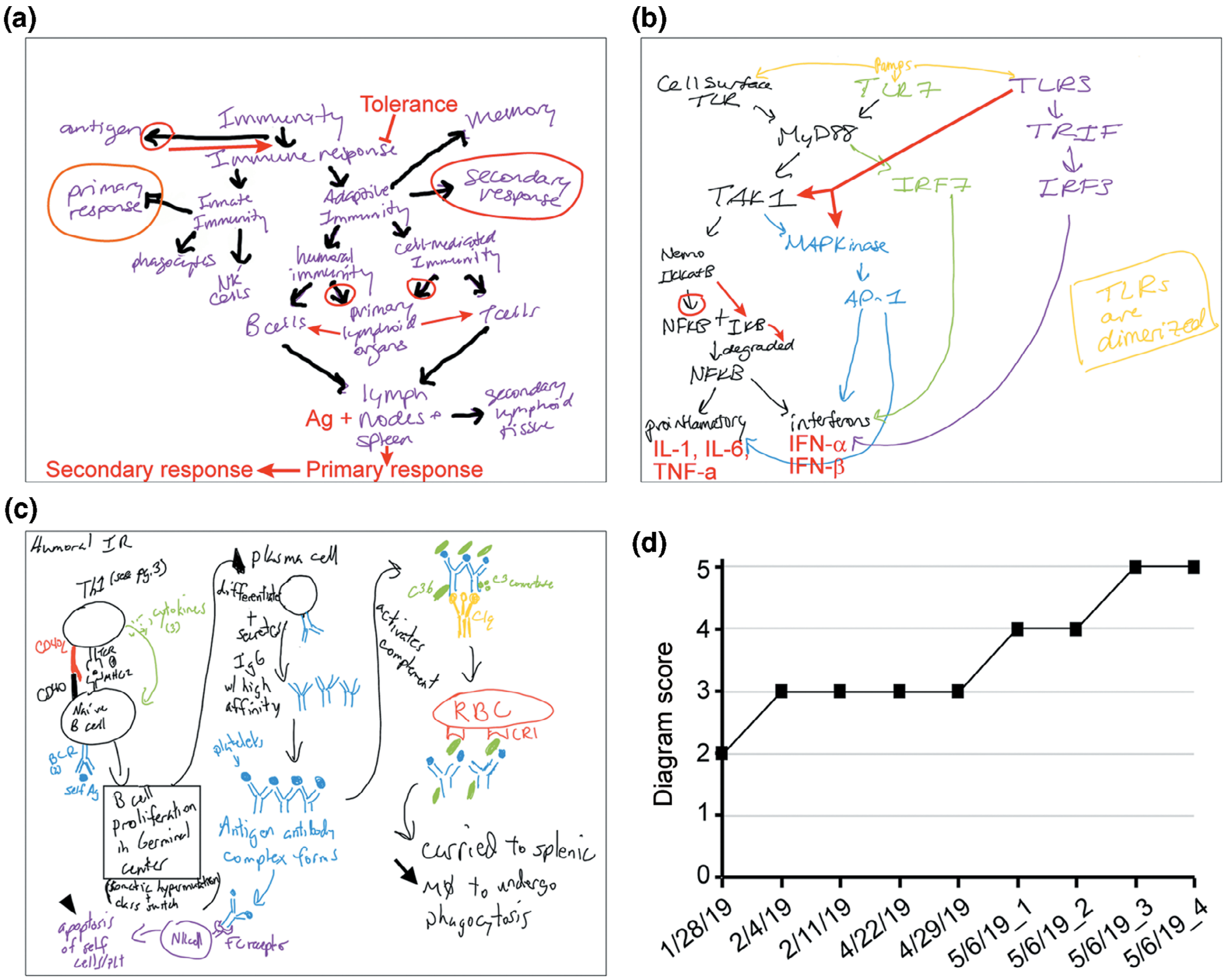


FIGURE 4 Deep learning facilitated by generating diagrams during MBCL in the Immunology class. The whiteboard results of a study group using diagrams were analyzed. (a–c) Three diagram examples are given. In (a) and (b), the red color illustrations were made by the instructor for grading purposes after the students had submitted their MBCL whiteboard results: Red circle for removing the inaccurate or incorrect molecular processes or concepts and red phrases for adding the correct or accurate molecular events. The red color illustrations in (c) were made by the students during their MBCL study. (d) The scores were determined according to the rubric for the nine diagrams generated by this MBCL group. There were four diagrams generated on May 6 [Color figure can be viewed at wileyonlinelibrary.com]

different dates: Jan. 28 (the first chapter-based MBCL study using diagram), Feb. 11 (the third chapter-based MBCL study using a diagram), and May 6 (the last MBCL activity of the core theme). As shown in Figure 4a, the first diagram generated by this group addressed most of the terms and relationships among these terms that were required by the MBCL assignment. However, there are more than three places of error or inaccurate molecular step or event. The diagram in Figure 4b, on the other hand, has fewer places of error or inaccurate concepts. When this group reached the final MBCL activity, the students were able to generate a complex diagram that showed the role of the humoral immune response in the pathogenic mechanisms of autoimmune disease—immune thrombocytopenic purpura (ITP) (Figure 4c and Table S2). Hence, these MBCL study results demonstrate the efficacy of the MBCL platform in scaffolding and promoting students' learning in knowledge recall, identification, integration, and synthesis over a semester. Indeed, this conclusion is confirmed by the trend of the increased grades of the students-generated diagrams, along with the increased number of MBCL studies (Figure 4d).

3.4 | The overall learning outcome of the MBCL studies

At the end of the last MBCL activity, we asked the students to complete and summarize their in-class studies as PowerPoint slides for an oral team presentation. We chose to quantitatively assess the PowerPoint slides of each study group to measure the overall educational outcome of the MBCL studies.

A rubric was generated with the consideration of students' skills in knowledge recall, knowledge integration, and knowledge synthesis (Figure 5a). Here, knowledge identification was considered as a part of the knowledge recall category. From one to five, the increasing grades correspond to the improved skills toward knowledge synthesis, which was treated as the highest rank of the thinking skills in the present study. As shown in Figure 5b, even though the three biology classes have different difficulty levels, the MBCL studies were able to achieve students' learning gains in deep learning, especially knowledge integration and synthesis.

3.5 | Comparison of the MBCL platform and the conventional method in promoting students' performance during cooperative learning

To test whether the MBCL platform provides an advantage compared to the conventional method of student-instructor interaction during cooperative learning, we conducted an experiment in the General Biology I Lecture class and the Genetics class in the fall semester of 2019. Here, the conventional method was considered as the usual interaction between the students and instructor, with which the instructor walked around the classroom to address students' questions when students raised their hands. For the MBCL platform, the instructor timely advised the students when the instructor identified any issues by monitoring the shared, instantly updated student whiteboards.

This comparison experiment consisted of two in-class group study activities: one with basic tasks and another with complex tasks. For each activity in a class, half of the groups used the conventional method, and the other half utilized the MBCL platform. Each group used the conventional method in one activity and utilized the MBCL platform for the other activity. The instructor was required to provide students suggestions of the study-related directions or issues without giving out the expected answers; the students had to figure out the solutions by themselves. This rule was to ensure the quality of the comparison experiment. In addition, the lively updated MBCL whiteboards were shown on the instructor's podium computer or iPad, instead of the classroom projection screen.

To generalize our rubrics for the use in different teaching subjects, we made a master rubric that was based on students' performance on identifying concepts or terms that were classified in different categories, integrating the identified terms into processes that were connected by arrows, and synthesizing mechanisms that could explain a real-life phenomenon (Figure 6a,b). Due to different natures of the study assignments in various teaching subjects, we further created the criteria to evaluate students' performance on knowledge identification on the terms of the categories (Figure S3), and a diversity of study assignments can be graded by selecting a different set of the scales from a) to l) (Figure 6a,b). The grading scales of knowledge integration and synthesis were able to be unified between the two classes (Figure 6b); it may be due to the similar critical thinking processes to integrate and synthesize knowledge for various study assignments. The detailed rubrics for each study activity in both classes were generated according to the master rubric (Tables S3–S6).

(a)

Score	Knowledge recall	Knowledge integration	Knowledge synthesis
1	3 or more missing taught key concepts	Key concepts not organized	Topic not explained by key molecular mechanisms
2	1 or 2 missing taught key concepts	Key concepts organized	Topic not explained by key molecular mechanisms
3	No apparent missing taught key concepts	Key molecular mechanisms presented	Topic not explained by key molecular mechanisms
4	No apparent missing taught key concepts	Key molecular mechanisms presented	Topic partially explained by key molecular mechanisms
5	No apparent missing taught key concepts	Key molecular mechanisms completed	Topic well explained by key molecular mechanisms

(b)

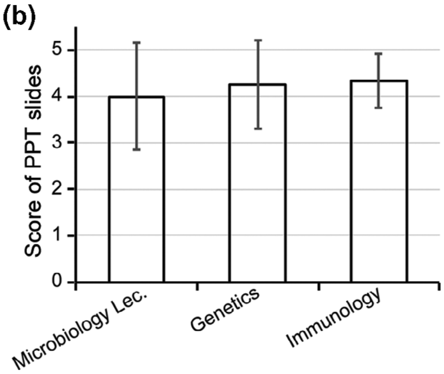


FIGURE 5 Quantitative analysis of the PowerPoint slides of the MBCL presentations in all three classes. (a) A rubric to grade the PowerPoint slides with the scale from one to five (low to high) was generated for assessing students' performance in knowledge recall, knowledge integration, and knowledge synthesis. (b) In the three classes, the scores of PowerPoint slides were determined for each MBCL group according to the rubric. For each class, the mean and standard deviation of the team scores are illustrated. Lec., lecture. Error bar: Standard deviation

(a)

Activities	Classes	Points (Total/activity: 15 points)														
		Task 1 (5 points)					Task 2 (5 points)					Task 3 (5 points)				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Activity 1: Basic tasks	BIOL 160	c)	e)	h)	k)	l)	a)	c)	e)	h)	k)	b)	d)	f)	i)	l)
	BIOL 360	a)	c)	e)	h)	k)	c)	e)	h)	k)	l)	b)	d)	f)	i)	l)
Activity 2: Complex tasks	BIOL 160 BIOL 360	c)	e)	h)	i)	j)	i)	ii)	iii)	iv)	v)	1)	2)	3)	4)	5)

(b)

Skills assessed	Rubric criteria
Knowledge identification Categories: Biological structures Terms: Structural components and functions	Increased scales of knowledge identification a) b) c) d) e) f) g) h) i) j) k) l)
Knowledge integration Categories: Biological pathways Relationship: Between molecules and pathways	i) 1 category with 1 arrow ii) 2 categories with 1 arrow/category iii) 2 categories with 2 arrows/category iv) 3 categories with 2 arrows/category v) 3 categories with 4 arrows/category
Knowledge synthesis Categories: Biological mechanisms Connection: Molecular mechanisms	1) 0 category with 2 connected terms 2) 1 category with 2 connected terms 3) 2 categories with 2 connected terms/category 4) 3 categories with 2 connected terms/category 5) 4 categories with 2 connected terms/category

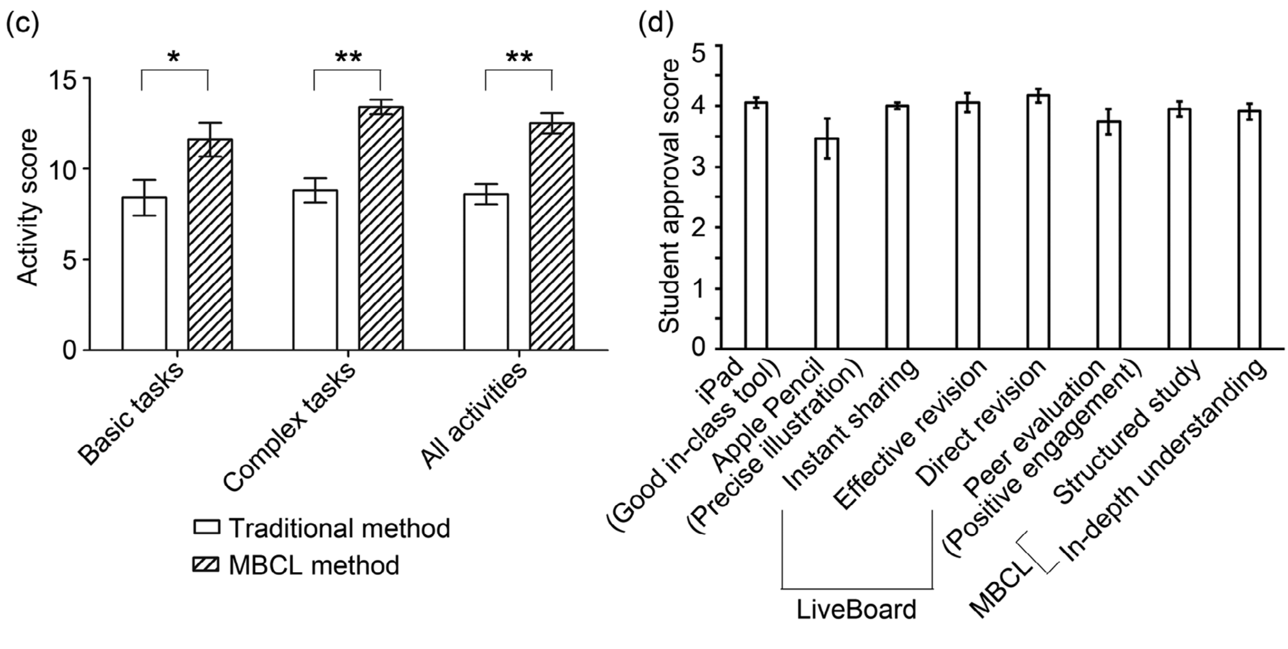


FIGURE 6 The comparison experiment and students' approval on MBCL. (a and b) A master rubric to assess students' group study results across disciplines in the comparison experiment. Two study activities were conducted in each of the two classes: General Biology I Lecture (BIOL 160) and Genetics (BIOL 360). Each activity consisted of three tasks of five points. For each of the knowledge identification tasks (all three tasks of activity 1 and task 1 of activity 2), the instructor selected five scales from a set of grading scales (Figure S3). For the knowledge integration and knowledge synthesis tasks (task 2 and task 3 of activity 2), both classes used the same grading criteria. (c) The cooperative learning results of the comparison experiment were graded according to their specific rubrics (Table S3–S6). All three analyses indicate that the average earned points of study results from MBCL-utilizing groups were statistically higher than those of the traditional method. Error bar: Standard error of the mean (* $P < 0.05$; ** $P < 0.01$). (d) The survey results of the 5-point Likert scale of the three classes were calculated as the approval mean scores. Error bar: Standard deviation

As shown in Figure 6c, the MBCL-utilizing groups achieved higher grades in both basic tasks and complex tasks. When all the study activities were combined, the MBCL-utilizing student groups also performed better (Figure 6c). Thus, the data indicate that when compared to the traditional method of student-instructor communication during in-class group studies, the MBCL platform can yield better students' learning gains in cooperative learning activities.

3.6 | Students' approval on the MBCL platform

In addition to the actual MBCL study results, we obtained students' opinions on the MBCL platform. After the MBCL activities were completed, student volunteers conducted a questionnaire in all the classes. The questionnaire consists of 16 questions that use the following ratings: Strongly Disagree (1 point), Disagree (2 points), Undecided/Neutral (3 points), Agree (4 points), and Strongly Agree (5 points), as well as a couple of yes or no questions to probe students' past experiences of in-class group study. All the students participated in the MBCL studies and responded to the survey (Table S7). The majority of the students in all three classes had participated in in-class group studies before their MBCL studies. The Microbiology Lecture class and Immunology class have more students who used the iPad in previous in-class group studies (40% and 40%, respectively) than the Genetics class (11%), although the differences are not statistically significant using Fisher's exact test (Genetics vs. Microbiology Lecture: Two-tailed $P = 0.07 > 0.05$; Genetics vs. Immunology: Two-tailed $P = 0.15 > 0.05$).

The mean score of each question was calculated for the three classes, and the scores ranged from 3.47 to 4.17 (Table S8). Thus, when we applied 3.00 as the cutoff for not being approved, including Strongly Disagree, Disagree, and Undecided/Neutral, the higher than cutoff mean scores indicated that the students overall agreed with these statements, approving the MBCL platform in facilitating cooperative learning. When we focused on the main statements (2, 3, 5, 7, 9, 13, 14, and 16) that describe the potential facilitating functions of the various components of the MBCL platform, as shown in Figure 6d, the students approved the iPad as a useful tool for cooperative learning (Statement 2: mean score = 4.05), LiveBoard in generating electronic whiteboards for instant sharing (Statement 5: mean score = 4.00) and easy revising (Statement 7: mean score = 4.05) and instructor's direct revision (Statement 9: mean score = 4.17), and the peer evaluation in promoting students' engagement (Statement 13: mean score = 3.74). The Apple Pencil has the lowest mean score of approval (Statement 3: mean score = 3.47). Nonetheless, the MBCL platform in facilitating structured group study and in-depth understanding have the approval equal to or greater than 3.91 (Statement 14: mean score = 3.95; Statement 16: mean score = 3.91), thereby approving the MBCL platform as an efficient mobile teaching platform for facilitating in-class cooperative learning.

4 | DISCUSSION

In the present study, we have established an iPad-based teaching platform called MBCL and used it in the Microbiology Lecture, Genetics, Immunology, and General Biology I Lecture courses. We have established the proof of principle of the MBCL platform in facilitating cooperative learning in regular college classrooms without special requirements of fixed classroom equipment. The MBCL platform streamlines the processes of setting up student groups using Blackboard, saving electronically cooperative learning results using Google Drive, and conducting peer evaluation through Google Forms. More importantly, the MBCL platform makes it available for the instructor to visualize the real-time process of students' group study. As a result, visible thinking generated by the MBCL platform allows the instructor to provide timely advice to guide students in conducting knowledge integration and synthesis, which are considered as deep learning and known to be the key elements of higher education.[30]

The teamwork results of the MBCL studies support the effectiveness of the MBCL platform in promoting deep learning toward knowledge integration and synthesis. Knowledge integration is a process to connect ideas to prior knowledge about a topic.[31] Closely related to knowledge integration, knowledge synthesis refers to the integration of findings from one study toward the understanding of a broader topic.[32] In the Microbiology Lecture class, because the students' study progress was visible to the instructor through the instantaneously updated electronic whiteboard, the instructor was able to capture students' study progress and suggest the students investigating further on the role of the CMAH enzyme. As a result, this team was able to conduct an in-depth study on the pathogenic mechanism of *S*. Typhi at the molecular level and evolutionary level (Table S2).

The above example suggests a mechanism for the MBCL platform in promoting deep learning, which is coherent with existing scientific findings. The real-time presentation of the students' group study process on the classroom projection screen gives rise to visible thinking. Visible thinking has been recognized as one of the critical requirements for effective, scaffolded knowledge integration.[33] Here, we propose an MBCL deep learning model in which students' cooperative study progress is available in real-time on LiveBoard. Such visible thinking can be captured timely by the instructor, who is responsible for guiding the cooperative learning process. The instructor thereby can advise students accordingly and instantly, and students can be guided to engage in additional cooperative study to achieve deep learning (Figure 7). The cycle of the MBCL deep learning triangle dynamically integrates students and the instructor toward an instructor-guided in-depth learning process.

The effects of the MBCL platform on promoting deep learning was further supported by the quantitative analysis on the MBCL study results in the Immunology class. We were able to demonstrate that conducting more MBCL studies corresponds to the increased student performance in knowledge recall, identification, integration, and synthesis (Figures 3 and 4). Furthermore, the quantitative measurement of the PowerPoint slides in all three classes, which are the final MBCL study outcomes, also supports the promotive effects of the MBCL platform on deep learning (Figure 5). Corroborating the objective data of students' MBCL study results, the subjective data of student approval support the positive effects of the MBCL platform (Table S8). On the other hand, we need to be cautious at interpreting the data presented in Figures 3e and 4d. Although the students likely improved their deep learning skills over a semester through the MBCL activities, we cannot exclude the contribution from other factors, such as the possibility that students became more familiar with instructor's requirements and expectations over a semester. To address this issue, we later conducted a comparison experiment in which the learning outcomes from MBCL-conducting students were compared to the study results of the students who did not use the MBCL platform. The data demonstrate that when compared to the traditional method of instructor's communication with students during in-class group studies, the MBCL platform can improve students' performance of cooperative learning (Figure 6c). Additionally, the generic master rubric used for grading various cooperative learning tasks in two classes of different teaching subjects may provide insight in designing a unified rubric to assess knowledge identification, integration, and synthesis across disciplines.

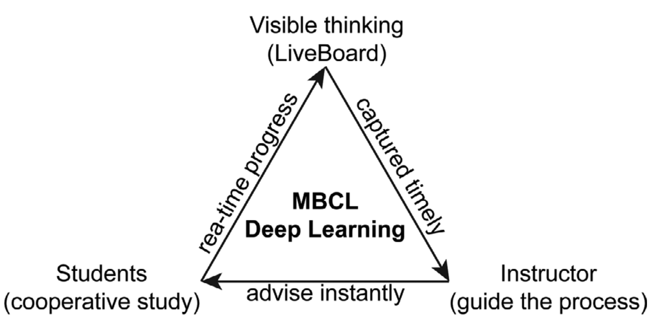


FIGURE 7 Model of MBCL deep learning triangle. The progress of students' cooperative learning is visible to the instructor in real-time. With insightful and timely advice, students can be promoted to engage in additional studies to achieve deep learning

Previous studies have explored the use of the iPad in facilitating undergraduate students' learning extensively.[19–21] Compared to some widespread use of iPads in teaching, such as taking notes, searching on the Internet, reading lecture slides, watching videos, and conducting virtual meetings,[22,23] the MBCL platform establishes a new way to address the issue of how to integrate the iPad technology for structured, innovative pedagogical methods to support the teaching process and curricula.[24] To use the MBCL platform, an instructor would get familiar with both the hardware and software. At Mercy College, we do so through faculty workshops. We anticipate a novice instructor could implement the MBCL pedagogy through 1 or 2 h of facilitated workshops and 1–2 h of self-study. During the first MBCL class, the instructor should allow time for students to learn and practice using the platform. It takes additional time to design well-structured group study contents.

The MBCL platform does not require specialized high-tech group study classrooms that need significant investment in fixed classroom equipment such as computers, wall-mounted computer screens, circular tables, and particular software.[17] The MBCL platform can be applied in typical college classrooms as long as the classroom has a podium computer, a projection screen, and a wireless Internet connection. The instructor can toggle between team whiteboards on the classroom projection screen. Thus, the MBCL platform does not impose a significant financial burden to students, instructors, and institutions in higher education except for purchasing a limited number of iPads and Apple Pencils. For example, in the present study, we only purchased four sets of the iPad and Apple Pencil for students in a class to use and carried these four sets to five different classes to conduct the MBCL activities. Similarly, a teaching department can purchase a set of iPads and Apple Pencils, which is very affordable compared to constructing a high-tech group study classroom, and multiple instructors can share them for use in their classes. Moreover, differentiated from some high-tech group study classrooms that use computers or laptops, the use of the iPad and Apple pencil gives the MBCL platform a unique function of promoting knowledge integration and synthesis through the freehand drawing of electronic diagrams and via the direct revision by the instructor.

Together, the present proof-of-principle study has established a new mobile technology-based platform MBCL that can facilitate in-class cooperative learning in a regular classroom to promote deep learning in higher education. As cooperative learning is a complex process that involves multiple aspects, including students' psychological states and team study skills, the current study paves the way for future studies to further develop MBCL's usefulness in promoting the efficacy of cooperative learning.

ACKNOWLEDGMENTS

This research project was supported by a Teaching Innovation Microgrant from Mercy College. The authors thank the students of the Microbiology Lecture class, the Genetics classes, the Immunology class, and the General Biology I Lecture class for participating in the research project and permitting the use of their study results for research and publication.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ORCID

Chun Zhou https://orcid.org/0000-0003-4114-0897

REFERENCES

1. Springer L, Stanne ME, Donovan SS. Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: a meta-analysis. Rev Educ Res. 1999;69:21–51.
2. Chang Y, Brickman P. When group work doesn't work: insights from students. CBE Life Sci Educ. 2018;17:ar52.
3. Hodges LC. Contemporary issues in group learning in undergraduate science classrooms: a perspective from student engagement. CBE Life Sci Educ. 2018;17:es3.
4. Sandeen C. High-impact educational practices: what we can learn from the traditional undergraduate setting. Contin High Educ Rev. 2012;76:81–9.
5. McLean M, Van Wyk JM, Peters-Futre EM, Higgins-Opitz SB. The small group in problem-based learning: more than a cognitive 'learning' experience for first-year medical students in a diverse population. Med Teach. 2006;28:94–103.
6. Johnson DW, Johnson RT. Instructional goal structure: cooperative, competitive, or individualistic. Rev Educ Res. 1974;44:213–40.
7. Cooper J, Mueck R. Student involvement in learning: cooperative learning and college instruction. J Excell Coll Teach. 1990;1:68–76.
8. Johnson DW, Johnson RT, Smith KA. Active learning: cooperation in the college classroom. 3rd ed. Edina, MN: Interaction Book Company; 2006.
9. Tanner K, Chatman LS, Allen D. Approaches to cell biology teaching: cooperative learning in the science classroom—beyond students working in groups. Cell Biol Educ. 2003;2:1–5.
10. Johnson DW, Johnson RT. An educational psychology success story: social interdependence theory and cooperative learning. Educ Res. 2009;38:365–79.
11. Davies WM. Groupwork as a form of assessment: common problems and recommended solutions. High Educ. 2009;58:563–84.
12. Kagan S. Kagan structures, processing, and excellence in college teaching. J Excell Coll Teach. 2014;25:119–38.
13. Wood WB. Innovations in teaching undergraduate biology and why we need them. Annu Rev Cell Dev Biol. 2009;25:93–112.
14. Dyer WGJ, Dyer JH, Dyer WG. Team building: proven strategies for improving team performance. 5th ed. San Francisco: Jossey-Bass, A Wiley Imprint; 2013.
15. Cohen EG, Lotan RA. Designing groupwork: strategies for the heterogeneous classroom. 3rd ed. New York: Teachers College Press; 2014.
16. Johnson DW, Johnson RT. Cooperation and competition: theory and research. Edina, MN: Interaction Book Company; 1989.
17. Soneral PAG, Wyse SA. A SCALE-UP mock-UP: comparison of student learning gains in high- and low-tech active-learning environments. CBE Life Sci Educ. 2017;16:ar12.
18. Kinash S, Brand J, Mathew T. Challenging mobile learning discourse through research: student perceptions of blackboard Mobile learn and iPads. Aust J Educ Technol. 2012;28:639–55.
19. Mango O. iPad use and student engagement in the classroom. Turk Online J Educ Technol. 2015;14:53–7.
20. DuBose C, Amienyi S, DuBose B. Analysis of an iPad initiative: are students using the technology? J Interdiscip Stud Educ. 2017;6:15–27.
21. Gong Z, Wallace JD. A comparative analysis of iPad and other m-learning technologies: exploring students' view of adoption, potentials, and challenges. J Liter Technol. 2012;13:2–29.
22. Hahn J, Bussell H. Curricular use of the iPad 2 by a first-year undergraduate learning community. Libr Technol Rep. 2012;48:42–7.
23. Fischer N, Smolnik S, Galletta D. Examining the potential for tablet use in a higher education context. In: Proceedings of the 11th International Conference on Wirtschaftsinformatik; February 27 - March 01, Leipzig, Germany, Vol. 1, pp. 9–22; 2013.
24. Nguyen L, Barton SM, Nguyen L. iPads in higher education—hype and hope. Br J Educ Technol. 2015;46:190–203.
25. Aggarwal P, O'Brien CL. Social loafing on group projects: structural antecedents and effect on student satisfaction. J Market Educ. 2008;30:255–64.
26. Davies LR, Varki A. Why is N-Glycolylneuraminic acid rare in the vertebrate brain? Top Curr Chem. 2015;366:31–54.
27. Schlenzka W, Shaw L, Kelm S, Schmidt CL, Bill E, Trautwein AX, et al. CMP-N-acetylneuraminic acid hydroxylase: the first cytosolic Rieske iron-sulphur protein to be described in Eukarya. FEBS Lett. 1996;385:197–200.
28. Chou HH, Takematsu H, Diaz S, Iber J, Nickerson E, Wright KL, et al. A mutation in human CMP-sialic acid hydroxylase occurred after the Homo-Pan divergence. Proc Natl Acad Sci U S A. 1998;95:11751–6.
29. Chou HH, Hayakawa T, Diaz S, Krings M, Indriati E, Leakey M, et al. Inactivation of CMP-N-acetylneuraminic acid

hydroxylase occurred prior to brain expansion during human evolution. Proc Natl Acad Sci U S A. 2002;99:11736–41.
30. Marambe KN, Edussuriya DH, Somaratne IS, Piyaratne C. Do medical students who claim to be using deep learning strategies perform better at the Forensic Medicine examination? South East Asian J Med Educ. 2009;3:25–30.
31. Hoadley CM, Linn MC. Teaching science through online, peer discussions: SpeakEasy in the knowledge integration environment. Int J Sci Educ. 2000;22:839–57.
32. Teel C. Creating curricular opportunities for knowledge synthesis. J Nurs Educ. 2014;53:431–2.
33. Linn MC. Designing computer learning environments for engineering and computer science: the scaffolded knowledge integration framework. J Sci Educ Technol. 1995;4:103–26.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Zhou C, Lewis M. A mobile technology-based cooperative learning platform for undergraduate biology courses in common college classrooms. *Biochem Mol Biol Educ*. 2021;49:427–440. https://doi.org/10.1002/bmb.21496