



Use of Digital Whiteboard to Engage Undergraduates in Online Studies of Instructor-Generated Biological Diagrams

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INTRODUCTION

Most undergraduate biology courses are packed with a large amount of knowledge. Navigating through many biological terms and concepts and mastering their related structures, functions, and mechanisms are key components of biology undergraduate students' study. Students' study in these aspects can be facilitated by effective critical thinking skills. Critical thinking involves comprehension, application, analysis, and synthesis, the higher order of cognitive skills in the hierarchy of Bloom's Taxonomy (1, 2). However, effective critical thinking skills can be challenging for undergraduate students to acquire, as indicated by some national assessments showing a lack of proficient critical thinking skills among college students (3).

Previously, we developed a mobile technology-based cooperative learning (MBCL) platform to engage students in generating diagrams and tables to think critically in undergraduate biology courses (4). Diagrams have been used to promote undergraduate students' learning and are a crucial form of visual literacy that is listed in the core competencies in the Vision and Change in Undergraduate Biology Education report (5, 6). Creating drawings such as concept maps and diagrams to illustrate the structure, relationships, and processes improves students' critical thinking skills in knowledge application, analysis, and synthesis of Bloom's Taxonomy (7). However, undergraduate biology students have been shown to have difficulties in comprehending diagrams, which may impede them from excising those higher-order skills in diagram-based activities (8). Using a provided visualization can enhance comprehension more than a learner-generated visualization approach (9). Thus, based on Vygotsky's zone of proximal development (ZPD) and the use of scaffolding in teaching

(10, 11), we thought to develop useful teaching tools to scaffold students' understanding of instructor-generated diagrams in which critical thinking of the functions and relationships of biological concepts is embedded. This more basic diagram study method is needed for teaching students how to conduct critical thinking in biology by comprehending and mimicking the critical thinking of a trained expert in the discipline, rather than using the common student-generated diagram and visualization approach in other studies (4, 12).

To this end, we chose to have students work on instructor-generated diagrams to study what they have learned in lecture classes. To conduct such activities distantly due to the COVID-19 pandemic, we have developed an online teaching tool for students to work on biological diagrams via a digital whiteboard. The critical thinking skills mainly include organizing concepts, identifying relationships among concepts, and integrating biological processes, which are embedded in students' working process on the diagram. In addition, the scaffolding process is established by providing hints in the diagram to help students identify the proper term or phrase for a diagram blank. Finally, such diagram activities can help students construct their knowledge via forming internal mental models of the learned biological contents, which in turn can facilitate students' understanding and memorization of principles, mechanisms, and other content knowledge (13, 14). Although developed for online use, this teaching tool can also be used in in-person classes and may be particularly useful for introductory courses and freshmen and sophomores.

PROCEDURE

The present teaching tool was used in two undergraduate introductory biology courses at Mercy College (NY), namely, General Biology I Lecture and General Biology II Lecture. In General Biology I Lecture, the diagram activities were conducted in the weekly recitation session provided by Mercy College's Peer-Led Team Learning (PLTL) program, and the peer leaders, students who had previously taken the course,

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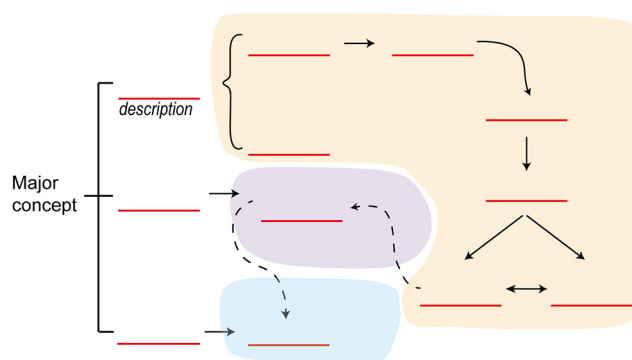
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served as the recitation leaders. In general, each peer leader worked with five to eight students for a semester. There were 10 diagram activities conducted for General Biology I Lecture. On the other hand, the instructor of General Biology II adopted the diagram activities for in-class discussion in several lecture classes, covering eight lecture topics, to test whether this online teaching tool could also be suitable for in-person classes as either in-class discussion or a combination of outside-class self-study and in-class discussion.

Zoom was used for holding online meetings for the diagram activities, which are referred to as a meeting, study activity, or recitation session in the present study. Other online meeting applications, such as Google Meet, Blackboard learning management system (LMS), and Canvas LMS, can also be used. We selected Microsoft Whiteboard as the online platform for students to work on the diagrams that were generated by the instructor. Microsoft Whiteboard is one of the electronic whiteboard applications that have been used for teaching. Microsoft Whiteboard enables multiple users to generate writings, drawings, or diagrams online simultaneously on a single shared digital canvas. While other whiteboard applications also provide instant online collaboration, such as Liveboard (4), BitPaper, Miro, Sketchboard, Conceptboard, and Explain Everything, most of them have adopted a fee for their full version and have limited functions for their free plans. In contrast, Microsoft Whiteboard is still free to use with a Microsoft account. Furthermore, previous studies have shown that Microsoft Whiteboard is able to benefit students for their understanding of the taught materials and promote student-teacher interaction in online classes (15, 16).

Each diagram study session was conducted for a period of 50 min. Students were provided with a diagram composed of key terms of a lecture and phrases related to the structures and functions of the terms. We also offered students several relevant multiple-choice questions for them to practice during the study session. The peer leaders and instructor moderated the study process to facilitate students' discussion via Zoom or in-person. Students were given time to work simultaneously on filling in the blanks in the diagram using the provided terms and phrases. Teamwork among students was encouraged for this process. The moderator, either a peer leader or the instructor, monitored students' performance on the digital whiteboard in real-time and addressed any issues or initiated conversations as appropriate. Thus, the moderator is responsible for scaffolding students' learning by explaining the hints, organization, relationships, and processes embedded in the diagram. Each student used a computer, laptop, tablet, or smartphone to participate in the diagram activity. To conduct a study session, the moderator first invited students to join an online Zoom meeting and then posted the Microsoft Whiteboard link in Zoom Chat. Students then accessed the digital whiteboard with this link with either a web browser or the downloaded Microsoft Whiteboard. For in-person classes, the instructor conducted the diagram activity by showing the diagram on the classroom projection screen, and students worked on the diagram using their personal laptop, tablet, or smartphone.



Please fill in the blanks using the following terms or phrases:

Axx	Bxx	Cxx	Dxx	Exx	Fxx
Gxx	Hxx	Ixx	Jxx	Kxx	Lxx

FIG 1. Schematic of the digital whiteboard with a diagram and its terms and phrases. The diagram is derived from a real whiteboard shown in Appendix 2 and models the study of a major concept that has three components. The red lines indicate the blanks to be filled using the terms and phrases provided below the diagram. The "description" represents a brief, relevant description underneath a blank to be used as a hint for filling in that blank. Three colored areas define the contents that belong to the three components of the major concept, respectively. Arrows indicate the relationships of the terms and phrases, and the dotted arrows show the relationship between two terms of different components. The terms and phrases are shown as a three-letter symbol and listed alphabetically.

The diagrams were generated by the instructor to scaffold students' learning of critical thinking skills through diagram studies. The instructor created the diagram and saved it as an image file, which was then inserted into a new whiteboard created in Microsoft Whiteboard and locked into the whiteboard background. That way, students were not able to move or change individual elements of the diagram when they conducted the diagram activity. In addition, the terms and phrases were pasted into the whiteboard as an image object to avoid any modification accidentally done by students during their study. To duplicate additional whiteboards for multiple peer leaders to use, we copied and pasted those image objects of the generated whiteboard into a newly created whiteboard. Fig. 1 shows a schematic of the electronic diagram and its terms and phrases. The detailed instructions for creating a whiteboard with a premade diagram and conducting the diagram activity are provided in Appendix 1. To summarize the possible uses of the present diagram study method and its scaffolding process, we have provided suggestions on how an instructor or a peer leader can organize and guide students through the diagram studies of three potential formats: online meeting, in-class discussion, and a combination of outside-class self-study and in-class discussion (Appendix 1). To illustrate how the diagrams are designed, an example is given for each of the two introductory biology courses, including the diagram (Appendices 2 and 6), terms and phrases (Appendices 3 and 7), and answer key (Appendices 4 and 8). We have also suggested some practicing questions that can be used to gauge students' learning gains from the above two diagram examples (Appendices 5 and 9) although those questions are not the

actual questions used in the recitation activities of the present study. Here, we have only included multiple-choice questions; short answer questions can also be adopted to promote students' analysis skills. All the remaining diagrams used in the General Biology I Lecture course are assembled in Appendix 10 for direct or customized use.

CONCLUSION

We have developed a learning tool for group studies of instructor-generated diagrams to nurture students' critical thinking skills. The customized use of Microsoft Whiteboard allows multiple students to work together to fill in the blanks of a well-designed diagram with certain complexity using the provided terms and phrases, which are derived from lecture slides and aligned with course learning objectives. Students can participate in the diagram activities online or in person with a computer, laptop, tablet, or smartphone. When implemented as either recitations or in-class discussions, this straightforward procedure for students to work on instructor-designed diagrams provides a means to promote students' learning of key concepts and mechanisms of biological courses.

Previous studies reported scaffolding methods in diagram activities, such as adopting an "expert skeleton" concept map to guide students to complete a more complex diagram using additionally suggested concepts (17). In the present study, each diagram was constructed to include both lower and higher levels of learning in Bloom's Taxonomy. The hints in the diagram allow the moderator, either a peer leader or instructor, to explain a target term to scaffold and promote students' learning of the taught knowledge. The organization of the terms and phrases into categories helps students apply the terms and their functions from their lecture classes to identify the relationships among the terms and build a whole picture of the learned knowledge. The arrows and shaded domains of different subcellular compartments or biological processes, on the other hand, can demonstrate how biological mechanisms and processes are analyzed in terms of spatial, temporal, sequential, and causal relationships (7, 13). Noteworthy, such diagram activities can help students construct their knowledge via forming internal mental models of the learned biological contents, which can promote students' understanding and memorization of the taught biological knowledge (13, 14).

The above-mentioned benefits of the reported diagram method are achieved via the facilitation of a peer leader or an instructor to guide students through the diagram study activity. In peer-leader-led recitations, we experienced both improved and non-improved performance of students on the practicing questions of a chapter. In the General Biology II Lecture class, however, the instructor observed an overall improved performance of students on practicing questions after the diagram study, with the caveat that the instructor only tested the diagram study for several lectures. Perhaps, having peer leaders trained properly for the diagram activities is key to scaffolding students' learning in peer-leader-led recitations. Ideally, a ZPD "cascade"

can be created. An experienced instructor trains peer leaders to improve their ZPD, which can help students in the class achieve a higher upper limit of ZPD via group discussion, consistent with other studies showing that conversation with peers improves students' ZPD for critical thinking (18).

This diagram teaching tool can also help visual learners and promote the visual literacy of undergraduate students (19). Dragging terms or phrases to fill in the diagram blanks may facilitate the study of kinesthetic learners. Group discussion can favor auditory learners. Further, both active learners and reflective learners may find this diagram method valuable as they can engage in the group study and have the opportunity to fill in the blanks individually during the teamwork. Real-time monitoring and interaction can secure students' active engagement in the diagram study for effective online learning (20). As hybrid courses have been suggested to play a more significant role in higher education due to the increased practice of online teaching and learning in response to the COVID-19 pandemic (21), the present teaching tool may help undergraduate students develop critical thinking skills and effective learning approaches in the postpandemic era.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 2.7 MB.

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