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Teaching Tools and Strategies

Adaptation and Facilitation of Small Group Activities in an Online Introductory Biology Class

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Abstract

In spring 2020, the sudden mid-semester closure of my campus in response to the global COVID-19 pandemic necessitated a rapid transition to emergency online learning. Consequently, I adapted the small group activities and facilitation methods of my face-to-face introductory biology class to a fully online format. During small group activities in the face-to-face classroom, students form teams of two or three and complete paper worksheets that are designed to promote dialogue among teammates, while learning assistants and I circulate around the classroom to provide assistance. Evidence suggests these small group activities are a highly effective form of active learning. Here, I describe how I adapted the content of these paper worksheets for use in my learning management system, how students performed collaborative group work together using videoconferencing software, and how learning assistants and I facilitated this group work in a completely online environment during the spring and summer 2020 semesters. I also discuss the limitations and benefits of online group work. Online group activities present many advantages over use of the same activities in the traditional face-to-face classroom including overcoming the many limitations of the physical classroom space.

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BENEFITS OF ACTIVE LEARNING

Since the publication of the AAAS call to action entitled, "*Vision and Change in Undergraduate Biology Education*," my introductory biology colleagues and I have increasingly incorporated active learning approaches into our teaching practices (1). This report challenged instructors to "step out from behind their comfort zone (the podium) and to spark student learning by 'being a guide on the side, not a sage on the stage'" (2). A large body of educational research indicating students benefit from active learning has been generated since this call to action. In a meta-analysis of 225 studies, Freeman et al. (3) demonstrated greater examination scores and a reduction of failure rates in undergraduate classes utilizing active learning strategies compared to those strictly employing traditional lectures. Active learning approaches that engage students cognitively, for example when students constructively interact with a partner such as a peer or instructor, are the most effective for learning (4). Interestingly, a survey of 431 instructors revealed that 48% felt their course evaluations increased, 32% felt that their course evaluations remained unchanged, and 20% felt that their student evaluations decreased when they attempted to incorporate active learning strategies into their introductory physics courses, thus an increase in course evaluations was the most likely outcome from integrating active learning into the classroom (5). These observations suggest both students and instructors directly benefit from using active learning strategies.

SMALL GROUP WORK AS AN EFFECTIVE ACTIVE LEARNING APPROACH

Active learning strategies are numerous and varied, and some examples that my colleagues and I use in our face-to-face classes include think-pair-share, live classroom polling, and small group activities. During think-pair-share activities, we present a question to students, provide time for students to individually consider the question, and encourage students to share their responses with a neighbor (6). Live classroom polling using classroom response systems such as "clickers" allows us to keep students engaged with course material by periodically posing questions and assessing student comprehension in real-time (7). During small group activities, students form teams of two or three and complete paper worksheets designed to promote dialogue among teammates. Paper worksheets include activities we have written ourselves or have taken from Trout (8), the HHMI BioInteractive website (https://www.biointeractive.org/, see "The Making of the Fittest" and "The Biology of Skin Color" for examples), and the QUBES hub website (see Cafferty (9) for example). Recently, Weir et al. (10) demonstrated group work using worksheets was the single most effective innovation to increase test scores in a study of active learning techniques used in different undergraduate biology courses. This suggests that our use of small group activities in the face-to-face classroom is a highly effective form of active learning.

A number of studies have revealed online teaching is as effective as traditional in-person instruction (11,12). Biel and Brame

(13) analyzed thirteen studies that compared the effectiveness of online and in-person undergraduate biology courses. The online courses that performed as well or better than face-to-face classes were well-designed and included features that promoted student-instructor and student-student interactions as typically take place during small group work. Thus, to encourage interpersonal interactions in my introductory biology course when transitioning to an online format, I converted the small group activities traditionally used in my face-to-face class for online use. Here, I will describe how I adapted and facilitated small group activities online midway through the spring semester and during the summer semester of the 2020 academic year.

ADAPTING PAPER WORKSHEETS FOR ONLINE GROUP WORK

I built the content of activities used as a paper handouts in my face-to-face introductory biology sections as ungraded practice quizzes in my class site on my institutional learning management system (LMS), Canvas. Some worksheets, including Process Oriented Guided Inquiry Learning (POGIL) activities, had images, models, and data tables that students analyzed by responding to guiding questions (14,15). These figures were included in online activities as downloadable PDF files to facilitate lining up images side-by-side with corresponding questions. Questions with limited numbers of possible answers were modified to a multiple choice or multiple answer format. This allowed for quantification of student responses enabling the rapid identification of challenging questions for post-activity discussion (Figure 1).

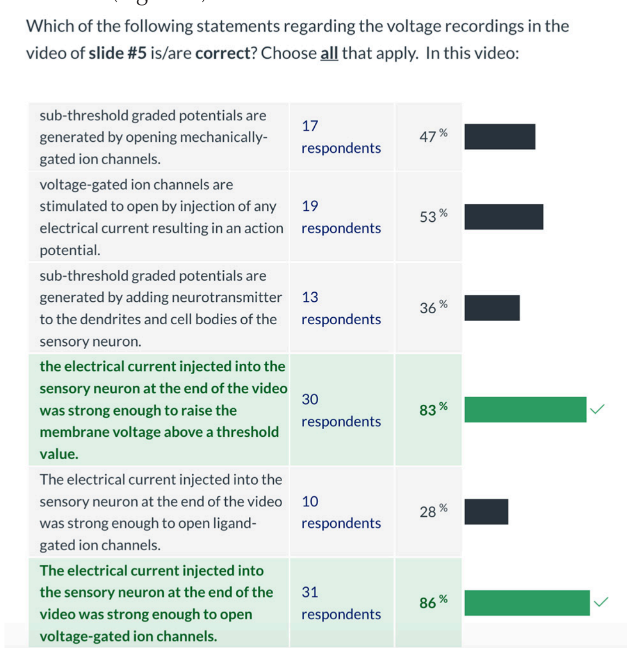


Figure 1. Sample multiple answer question with quantified student responses. Quantified student responses to activity questions become available immediately following activity submission in my LMS. This allows me to identify questions and concepts that students found challenging for further discussion. In this example of a multiple answer question, correct responses are indicated with check-marks and are highlighted in green. While the majority of students (83% and 86%) identified the two correct answers, some students also selected each of the incorrect responses. This question was taken from Cafferty (9), a guided inquiry activity written to accompany the HHMI BioInteractive Click-and-Learn entitled "Electrical Activity of Neurons" found here: https://www.biointeractive.org/classroom-resources/electrical-activity-neurons. The entire guided inquiry activity, along with teaching resources and an answer key, can be downloaded from the QUBES hub site here: https://qubeshub.org/publications/1405/1.

Multiple choice and multiple answer questions were followed by open-ended questions that asked student groups to explain their answers to the preceding question to provide further insight into why student groups selected particular response options (Figure 2). Some questions on paper worksheets were not directly compatible with available question formats in our LMS and required modification, increasing the amount of time needed to build activities. For example, data tables on paper worksheets required being broken down into multi-part, open-ended questions to maintain the learning objectives of the original activities (Figure 3). For questions requiring student drawings, for example of cellular structures or concept maps, students were invited to use any drawing software of their choosing to create their illustrations, including OneNote, GoodNotes, or Notability, or to hand draw figures, take a picture, and upload files as JPGs or PDFs into the online activity (Figure 4). Answers were built into online activities allowing students to check their work upon activity completion (Figure 5).

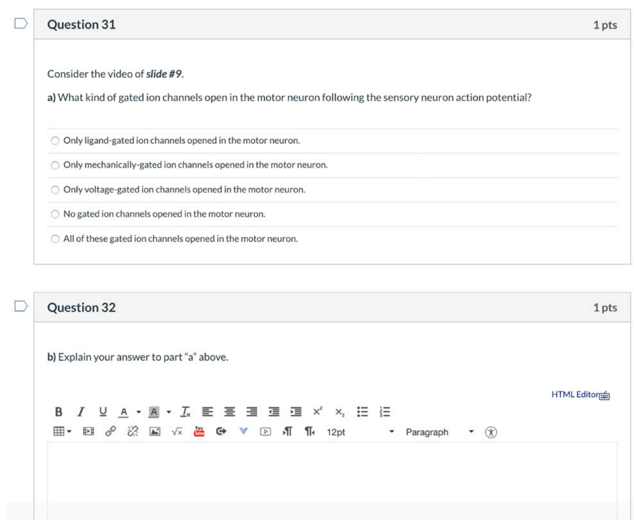
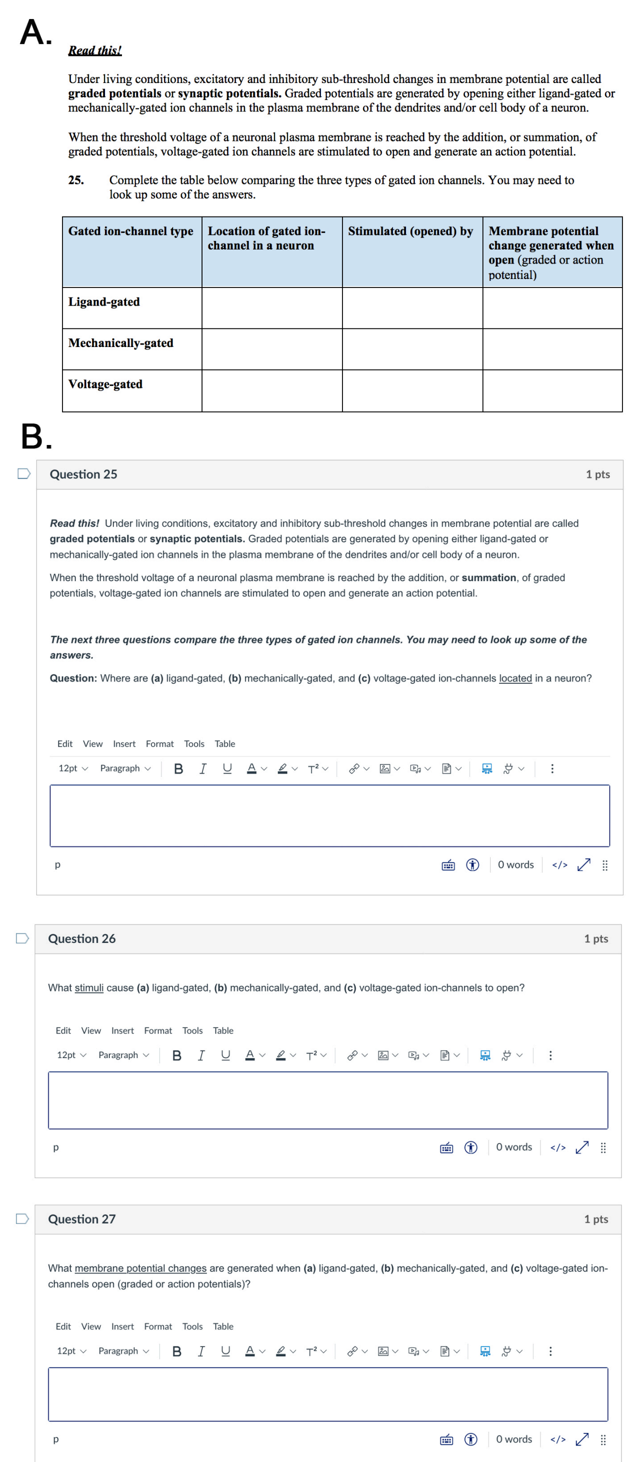


Figure 2. Two-part question with a multiple choice and an open-ended question component. A multiple choice question offers quantified student responses that can allow me to quickly identify challenging questions during post-activity review, while the following open-ended question can provide insight into why student groups chose particular response options. This question was taken from Cafferty (9).

Designing group activities in our institutional LMS offers a number of distinct advantages over building these activities on other non-institutional websites. For example, LMS activities are easy for students to find as they are in the same location as all other related class materials. In addition, I build the formative and summative assessments for my online course in my LMS, thus group activities offer students a low-stakes opportunity to practice answering similar questions in the same environment as these assessments. Questions built in our LMS are added to an LMS test bank. I pull these test bank questions for modification when building quizzes and exams, aiding the alignment of assessments with course activities. Finally, online activities in the LMS are easy to copy between multiple sections of the same course, and into future sections of the same course.



A.

Read this!

Under living conditions, excitatory and inhibitory sub-threshold changes in membrane potential are called **graded potentials** or **synaptic potentials.** Graded potentials are generated by opening either ligand-gated or mechanically-gated ion channels in the plasma membrane of the dendrites and/or cell body of a neuron.

When the threshold voltage of a neuronal plasma membrane is reached by the addition, or summation, of graded potentials, voltage-gated ion channels are stimulated to open and generate an action potential.

25. Complete the table below comparing the three types of gated ion channels. You may need to look up some of the answers.

Gated ion-channel type	Location of gated ion-channel in a neuron	Stimulated (opened) by	Membrane potential change generated when open (graded or action potential)
Ligand-gated			
Mechanically-gated			
Voltage-gated			

B.

Question 25 1 pts

Read this! Under living conditions, excitatory and inhibitory sub-threshold changes in membrane potential are called **graded potentials** or **synaptic potentials.** Graded potentials are generated by opening either ligand-gated or mechanically-gated ion channels in the plasma membrane of the dendrites and/or cell body of a neuron.

When the threshold voltage of a neuronal plasma membrane is reached by the addition, or **summation**, of graded potentials, voltage-gated ion channels are stimulated to open and generate an action potential.

The next three questions compare the three types of gated ion channels. You may need to look up some of the answers.

Question: Where are **(a)** ligand-gated, **(b)** mechanically-gated, and **(c)** voltage-gated ion-channels located in a neuron?

Edit View Insert Format Tools Table

12pt Paragraph

p 0 words

Question 26 1 pts

What stimuli cause **(a)** ligand-gated, **(b)** mechanically-gated, and **(c)** voltage-gated ion-channels to open?

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Question 27 1 pts

What membrane potential changes are generated when **(a)** ligand-gated, **(b)** mechanically-gated, and **(c)** voltage-gated ion-channels open (graded or action potentials)?

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Figure 3. Some questions on paper worksheets are not directly compatible with available LMS question formats. (A) Example of a table taken from Cafferty (9) that required modification for inclusion in an online activity. (B) The table from (A) was broken down into three (Questions 25-27) multipart (a-c) open-ended questions to maintain the learning objective of the original activity.

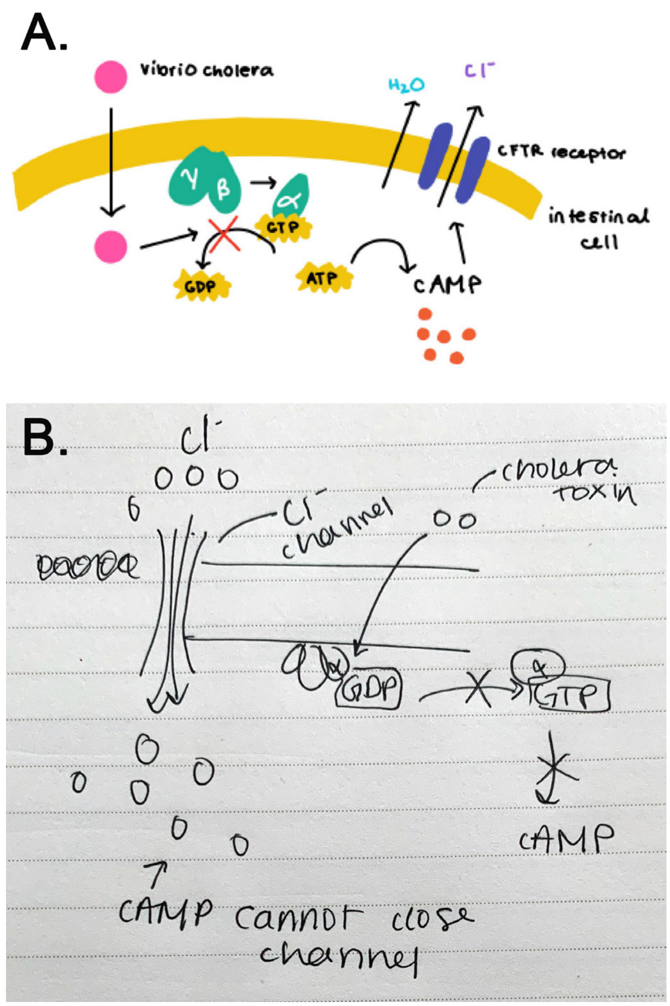
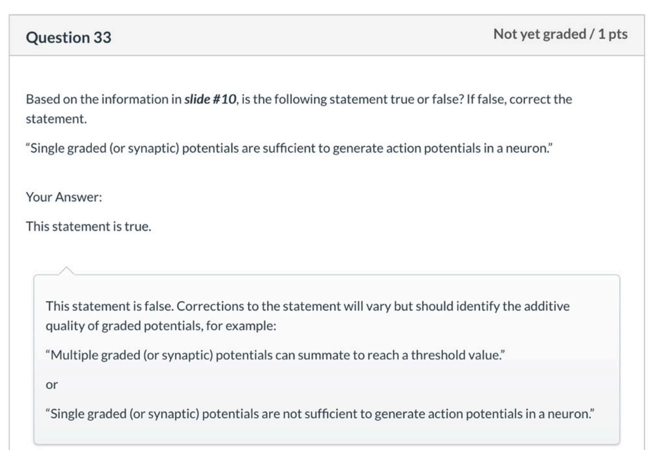


Figure 4. Sample responses by two different student groups to a drawing question in a cell signaling group activity. (A) An example of an illustration created using drawing software. (B) An example of an illustration drawn by hand.



Question 33 Not yet graded / 1 pts

Based on the information in ***slide #10***, is the following statement true or false? If false, correct the statement.

"Single graded (or synaptic) potentials are sufficient to generate action potentials in a neuron."

Your Answer:

This statement is true.

This statement is false. Corrections to the statement will vary but should identify the additive quality of graded potentials, for example:

"Multiple graded (or synaptic) potentials can summate to reach a threshold value."

or

"Single graded (or synaptic) potentials are not sufficient to generate action potentials in a neuron."

Figure 5. Open-ended question with sample student response and feedback. After submission of a completed activity, students can compare their work with the built-in answer key to self-assess their learning. This question was taken from Cafferty (9).

FACILITATING GROUP WORK DURING SYNCHRONOUS ONLINE CLASS PERIODS

Online educational activities can be classified as being asynchronous, that students complete on their own time (out-of-sync), and synchronous, when students meet online at the same time to work together (in sync). While asynchronous course material offers maximal flexibility in terms of when students interact with course content, asynchronous work can also contribute to social isolation as students must wait for peer or instructor feedback (16). In a comparison of these two educational approaches, Hrastinski (16) revealed students felt more psychologically aroused and motivated during synchronous tasks. Hrastinski (16) concluded synchronous and asynchronous online learning activities are complementary and recommended that instructors adopt a combination of both methods in their online course design. Consistent with these recommendations, my online introductory biology course is composed of both asynchronous and synchronous components.

Small group work takes place during live, synchronous sessions when the entire introductory biology class meets together online using Zoom video conferencing software. Students work on online activities in teams of three in virtual breakout rooms determined randomly by the videoconferencing software. The random determination of groups ensures that, from one activity to the next, students have an opportunity to meet and work with different students and only students present with working internet connections are placed into groups. Once students enter their breakout rooms, they self-select one of three defined team roles, including the roles of reader, reporter, and recorder. Students enter their chosen roles in the first question box of the activity, as well as change their screen name in the videoconferencing software to reflect their preferred name, activity role, and pronouns (for example, Patrick – Reader – He/His/Him). Sample instructions for a synchronous small group activity are found in S1 (S1. Small group activities online – Sample student instructions). The format of online group activities and roles used during these sessions is introduced with an ice-breaker activity during the first online synchronous session. Following this introduction, students do not require instructions beyond those found in S1 during future activities. Implementation of and student buy-in for small group activities was similar for students in the spring cohort, who initially met their peers in the face-to-face classroom, and for summer students who took the class completely online.

Students proceed through the online activity according to their chosen roles. The team's reader reads the text of the activity out-loud to their teammates, which helps keep everyone on track. Following group discussion, the recorder types the group's consensus answers to questions into the activity. Teammates can more easily provide input to their work when the recorder shares their screen with their group throughout the activity. Finally, the reporter shares group responses to questions with the rest of the class at the end of the synchronous session. Other roles occasionally used during group activities include the timekeeper, who keeps track of time and encourages their group to move on if they are taking too long to answer particular questions, and the spokesperson who presents the work of their team to another group and returns to their team to deliver feedback. More details about the benefits and use of activity roles during small group work, and further examples of alternative roles, are found in Hoffman and Richardson (17).

Student groups and roles are organized in a similar manner during in-person and online versions of my introductory biology class. In face-to-face classes, students choose teammates for each small group activity. While the composition of student groups vary from class-to-class, students generally chose teammates who sit nearby in the physical classroom, so groups are not formed in a truly random manner as is done online. In both online and in-person classes, students chose activity roles within their groups. Approximately two-thirds of students in both online and face-to-face classes perform the roles of reader, recorder, and reporter equally by the end of the semester and report a desire to be cooperative with their teammates when selecting their role (unpublished findings). For example, during the online portion of the spring 2020 semester, one student reported in an anonymous survey, "I'm usually flexible and chose a role based around what my classmates prefer and try to perform each role equally." A small number of students report a strong preference for a particular role, including another student who responded on the same survey, "I chose this role because reading material out loud allows me to internalize the concepts better." In future online and face-to-face sections of introductory biology, I plan to periodically assign a "reflection report" following small group activities to encourage students to consider how well they performed their individual roles and how they worked together as a group. These reports may provide further insight into whether all students participate equally using their roles and the effectiveness of their group work.

While students follow prompts and answer questions in a group activity, undergraduate learning assistants (LAs) and I act as facilitators and move from one breakout room to the next to monitor progress and answer questions when needed. During each activity, facilitators are assigned a set number of breakout rooms to monitor. Also, students within a breakout room can raise a "virtual hand" to seek more immediate assistance. Importantly, facilitators do not directly answer activity questions for students, but instead ask probing questions or provide hints to help guide student groups in the right direction. This practice is consistent with observations by Knight et al. (18) who, in a study of student interactions with LAs during clicker-question discussions, found that question prompts by LAs promoted student use of reasoning. During the final 10-15 minutes of synchronous class, students are brought together for a discussion of the synchronous activity. Students are encouraged at regular intervals to ask questions during class discussions using their microphones or may alternatively ask questions at any time using the chat feature of the videoconference. LAs continually monitor the chat feature and provide an immediate response to these questions. During our discussion, students' preferred names, activity roles, and pronouns continue to be shown in their video conferencing screen names, allowing reporters to be called on appropriately to report out the work of their groups.

ASSESSMENT OF LEARNING

Learning is assessed regularly using weekly assignments in addition to midterm and final exams. During the spring and summer 2020 semesters, these assessments were comprised of multiple choice, multiple answer, and true and false questions for ease of grading. Weekly assignments are composed of 10 automatically-graded questions, are made available for a week-long period, assess material from the previous week and thus can be completed once open, and can be taken at any time.

Weekly assignments are not proctored, but are set to present one question at a time without backtracking, and present questions and response options in random order to encourage individual assignment completion. See Figure 6 for an example of a weekly assignment question aligned with a learning objective covered by an online group activity. Final exams taken during the emergency online learning portion of the spring 2020 semester were take-home, closed book, and not proctored as these students had not previously had an opportunity to take a virtually proctored exam. During the summer 2020 semester, students took two midterms and one final exam that were live-proctored virtually using the service, Examity.

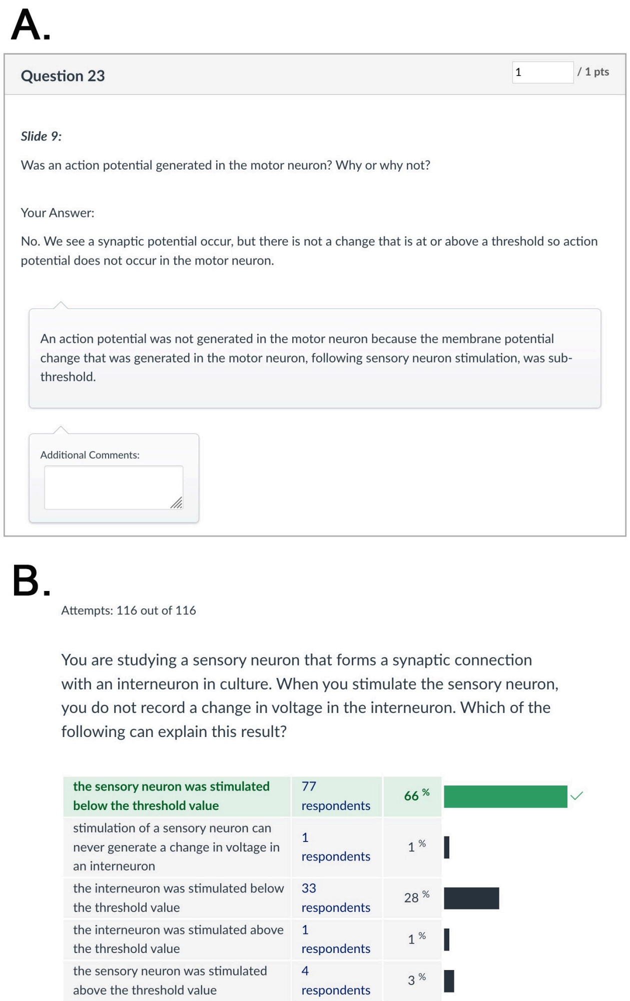


Figure 6. Learning is assessed using weekly assignments. (A) Question 23 is one of a series of activity questions that guide students through the communication of two neurons in culture and was taken from Cafferty (9). (B) A sample weekly assignment question that assesses the neuronal communication learning objective associated with (A). The correct response is indicated with a check-mark and is highlighted in green. Some students selected each of the five possible answers and 66% of students chose the correct answer. Further discussion of this learning objective was provided during the next synchronous class session following this result.

LIMITATIONS OF ONLINE GROUP WORK

Building online activities is a time-intensive process. Depending on the length of an activity, and number of questions and images that must be modified from their original format, I spend between 1-2 hours building an activity in our LMS. However, once activities are built, they can easily be shared among different course sections and used over multiple semesters. In fact, I plan to use these LMS group activities in my future face-to-face introductory biology classes in order to take advantage of quantified student responses during end-of-class discussions (see Figure 1 for example). Use of LMS group activities in the face-to-face classroom will also save distribution and collection time and the environmental and economic costs associated with using paper worksheets.

Other limitations of using group activities online include access, technical challenges, and privacy issues. Participation in online group activities during synchronous class sessions requires each student to have access to computer equipment with a strong enough internet connection for live video conferencing as well as a quiet environment with limited distractions. Groups can be left without a teammate for a period of time when unexpected technical issues arise and require troubleshooting. Users can unintentionally interrupt each other due to lag over videoconferencing software. Also, facilitators miss important information that they could quickly pick up when surveying an entire in-person classroom, which is not possible when students are contained in breakout rooms. Finally, students may also not want to share their home environment with others via webcam, and become hidden from view when they leave their webcams off, which can hinder communication between teammates. However, use of the virtual background feature in videoconferencing software can be helpful to maintain a degree of privacy with webcams turned on. To facilitate group work for students unable to work synchronously, O'Brien (19) has modified guided inquiry activities for an asynchronous chemistry class and recommends making activity completion a collaborative team effort.

BENEFITS OF ONLINE GROUP WORK

Online group work offers many distinct advantages over similar work in the face-to-face classroom. For instance, online group work overcomes limitations of physical spaces. I teach my face-to-face introductory biology class in a tiered auditorium with fixed seating. Oftentimes during group work, students must sit awkwardly in their seats or sit on the floor in order to face each other to see their group's worksheets. When students sit on the auditorium floor, passageways are blocked making facilitation a challenge.

Online group work is more equitable for students and faculty with disabilities. In the face-to-face class, only the front row of our tiered auditorium is accessible to students who have physical disabilities and/or use guide dogs. Consequently, students with disabilities are restricted to working with only the other students who sit in the front row. In the online environment, any student can potentially work with any other student in the class, regardless of physical abilities. Similarly, once the auditorium aisles are full, it can become difficult for facilitators to navigate the room. To reach certain groups, facilitators may need to climb up the room over the backs of chairs. Not all facilitators want or are able to climb over desks and chairs to reach students. Finally, the noise level in an auditorium with a large number of active groups (typically > 100 students) gets very high, making it difficult for students and facilitators to hear each other. This presents a barrier to communication for students and faculty with any form of hearing impairment or auditory sensitivity that does not exist in a virtual breakout room of only 3-4 people.

Activity facilitation is improved in the online environment as my LAs and I can move from one group to the next at the click of a button. This better allows us to spend an equal amount of time with each student group and to quickly respond to questions as they arise. Additionally, we can see the preferred names and pronouns of each student on their screen names and thus we are more easily able to communicate with students appropriately online.

FINAL THOUGHTS

In spring 2020, the sudden closure of my campus in response to the COVID19 pandemic led my students to return to homes across the United States as well as internationally including to countries such as China, India, Singapore, South Korea, and Taiwan. Though all of my students had internet access, many were taking a full course load from a location with a 9-12 hour time difference. Students who could not participate in some or all of our synchronous class sessions for any reason, including the time difference, technical difficulties, or illness, were encouraged to complete class activities on their own. Prior to registration for summer 2020 online classes, the days, times, and format of required weekly synchronous sessions was published in the institutional course atlas, making students aware of this commitment upfront. During the rare occasion when students were absent and excused from a synchronous class, for example due to computer failure, they completed missed activities on their own and received credit. Many students successfully completed the summer course from China and India and reported that the time difference was manageable when only taking 1 or 2 courses as opposed to a full course load of approximately 5-7 classes.

Based on anonymous survey responses (n = 122) during the spring and summer 2020 semesters, most students had a positive experience completing small group activities online. For example, 75% of students either strongly agreed or agreed with, and 20% felt neutral about the statement, “The synchronous group activities helped me in this course.” Some students commented that the small group activities increased the sense of community within the course, for instance one student wrote, “In most of my other online lecture courses, it is very difficult to develop any sort of sense of community; I feel that I don’t know my fellow classmates at all. The synchronous activities in introductory biology, however, successfully created a sense of community, introduced students to their classmates, and helped students gain a better understanding of course material.” A number of students recommended reducing the amount of class time spent on synchronous activities to allow for more time for an introduction and review. In the future, a portion of longer activities could be assigned as homework in order to free up more class time. A small number of students requested “more lecture time instead of group activities.” This suggests that I should continue to explain the purpose and benefits of active learning approaches such as use of group activities to further solicit student buy-in. Based on the positive feedback from the spring and summer 2020 semesters, I will continue to use small group activities in future online sections of my introductory biology class.

Varty (20) surveyed the 2015-16 academic year course schedules of 96 American institutions of higher education to document the availability of online biology courses. This work revealed only a limited number of types of undergraduate biology courses were being offered online. In 2015-16, most available online classes targeted non-biology majors who were either completing prerequisites for healthcare-related programs or science general education requirements at 2-year public colleges. The unexpected closure of college campuses in response to the global COVID19 pandemic has forced all instructors to suddenly become creative with what courses we teach, and how we teach them online. It will be exciting to see what innovative approaches to teaching and learning arose during the pandemic as more instructors share their work, as well as to learn what variety of courses continue to be offered online in the future.

SCIENTIFIC TEACHING THEMES

Active Learning

Use of small group activities during synchronous class sessions promotes student dialogue and keeps students actively engaged with course material. Recent work by Weir et al. (10) demonstrates group work using activities is an effective active learning tool to increase the test scores of undergraduate biology students.

Assessment

Small group activities completed during synchronous class sessions are an ungraded learning tool judged solely on the basis of completion. However, these activities are aligned with course learning objectives that are assessed using assignments and exams. Activity questions built into our institutional learning management system are entered into a test bank and these questions are later retrieved and modified when building assignments and exams. Students assess their learning during post-activity discussions held at the end of synchronous class sessions as well as by comparing their group answers to answer keys built into the activities.

Inclusive Teaching

Use of specific roles during small group activities provides clear expectations for and more evenly divides labor among students, allowing all students the opportunity to participate (17). In addition, use of small group activities in synchronous class sessions increases class structure. Past work by Eddie and Hogan (21) has revealed increasing class structure greatly reduces achievement gaps between black and white students and first-generation and continuing-generation students. Changing screen names in videoconferencing software to reflect pronouns acknowledges diversity in the classroom and normalizes the practice of sharing pronouns which may help make the synchronous classroom environment a more welcoming place. Past work by Cooper and Brownell (22) has revealed LGBTQIA students do not perceive the biology classroom community as a welcoming space for their identities.

SUPPORTING MATERIALS

S1. Small Group Activities Online – Sample Student Instructions

ACKNOWLEDGMENTS

PC would like to thank his introductory biology students for the dedication and persistence they demonstrated during online group activities throughout the emergency online learning portion of the spring 2020 semester. PC would also like to thank his colleagues who teach introductory biology for their continued assistance and support throughout the COVID19 pandemic.

REFERENCES

1. AAAS. 2011. Vision and Change: A Call to Action, Washington, DC: AAAS. Available from: http://visionandchange.org/finalreport/.
2. McLaughlin J and Metz M. 2016. Vision and change: why it matters. The American Biology Teacher. 78(6):456-462. https://doi.org/10.1525/abt.2016.78.6.456.
3. Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP. 2014. Active learning boosts performance in STEM courses. Proceedings of the National Academy of Sciences, 111(23):8410-8415. https://doi.org/10.1073/pnas.1319030111.
4. Chi MT and Wylie R. 2014. The ICAP framework: Linking cognitive engagement to active learning outcomes. Educational Psychologist, 49(4):219-243. https://doi.org/10.1080/00461520.2014.965823.
5. Henderson C. 2018. Will my course evaluations decrease if I adopt an active learning approach? American Journal of Physics, 86(12):934-942. https://doi.org/10.1119/1.5065907.
6. Freeman S, O'Conner E, Parks JW, Cunningham M, Hurley D, Haak D, Dirks C, Wenderoth MP. 2007. Prescribed active learning increases performance in introductory biology. CBE Life Sciences Education, 6(2):132-139. https://doi.org/10.1187/cbe.06-09-0194.
7. Kaddoura M. 2013. Think Pair Share: A teaching learning strategy to enhance students' critical thinking. Educational Research Quarterly, 36(4):3-24.
8. Trout L., editor. 2012. POGIL Activities for AP Biology. (1(st) ed.) Batavia, IL: Flinn Scientific.
9. Cafferty P. 2019. Electrical and chemical communication in the nervous system. HHMI BioInteractive A&P FMN (2019), QUBES Educational Resources. doi:10.25334/7JK1-E403.
10. Weir LK, Barker MK, McDonnell LM, Schimpf NG, Rodela TM, Schulte PM 2019. Small changes, big gains: A curriculum-wide study of teaching practices and student learning in undergraduate biology. PLoS ONE, 14(8). https://doi.org/10.1371/journal.pone.0220900.
11. Ahern K. 2017, Teaching biochemistry online at Oregon State University. Biochemistry and Molecular Biology Education, 45(1):25-30. https://doi.org/10.1002/bmb.20979
12. Carrol N and Burke M. 2010. Learning effectiveness using different teaching modalities. American Journal of Business Education, 3(12):5-76. https://doi.org/10.19030/ajbe.v3i12.966
13. Biel R and Brame CJ. 2016. Traditional versus online biology courses: Connecting course design and student learning in an online setting. Journal of Microbiology and Biological Education, 17(3):417-422. Doi: 10.1128/jmbe.v17i3.115
14. Hanson DM and Moog RS. 2006. Introduction to POGIL. Available from: http://www.pcrest.com/PC/pub/POGIL.htm (Retrieved July 11, 2020)
15. Moog RS and Spencer JN. 2008. "POGIL: An Overview" (Process Oriented Guided Inquiry Learning). Washington, DC: American Chemical Society; 1(st) edition. 1-13.
16. Hrastinski S. 2008. Asynchronous and synchronous e-learning. Educause Quarterly 31(4):51-55.
17. Hoffman MM and Richardson S. 2019. Team construction and accountability. In Simonson SR editor. POGIL: An introduction to Process Oriented Guided Inquiry Learning for those who wish to empower learners. Sterling, VA: Stylus Publishing. P. 113-140.
18. Knight JK, Wise SB, Rentsch J, and Furtak, EM. 2015. Cues matter: Learning assistants influence introductory biology student interactions during clicker-question discussions. CBE Life Sciences Education 14(4):ar41. https://doi.org/10.1187/cbe.15-04-0093
19. O'Brien S. 2020 (April 19). POGIL activites in an asynchronous learning environment. Chem Ed Xchange, Available from: https://www.chemedx.org/blog/pogil-activites-asynchronous-learning-environment (Retrieved July 11, 2020)
20. Varty AK. 2016. Options for online undergraduate courses in biology at American colleges and universities. CBE Life Sciences Education 15(4)ar58. https://doi.org/10.1187/cbe.16-01-0075
21. Eddy SL and Hogan KA. 2017. Getting under the hood: How and for whom does increasing course structure work? CBE Life Sciences Education 13(3):453-468. https://doi.org/10.1187/cbe.14-03-0050
22. Cooper KM and Brownell SE. 2016. Coming out in class: Challenges and benefits of active learning in a biology classroom for LGBTQIA students. CBE Life Sciences Education 15(3):ar37. https://doi.org/10.1187/cbe.16-01-0074.