Promoting student interaction, engagement, and success in an online environment

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Introduction

Methods that engage students in the learning process are superior to didactic, lecture-based instruction [1–7]. Students must actively develop their capabilities to become more expert, often collaboratively, with ongoing guidance from a faculty member [3]. The use of small-group, active learning exercises in the classroom leads to improvements in academic achievement, better reasoning and critical thinking skills, increased retention of students, and improved relationships with faculty and other students [7–14]. However, a survey of nearly 6000 students and faculty after the initial phase of remote learning at Indiana University found few online classes were able to provide these types of interactive learning experiences. Students had fewer interactions with faculty and other students which led to increased difficulty in completing course assignments and a decreased sense of belonging in the university system [15]. Recommendations from this survey for future online courses included creating opportunities for communication between students and instructors and fostering a sense of community through virtual student-to-student interactions [15].

This contribution is part of a series featuring teaching analytical science during the pandemic in order to support instructors in preparing their courses.

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Four instructors who use active learning in their face-to-face classes will describe various ways to create collaborative virtual classes that engage students in the learning process. Solutions to various challenges to student engagement during remote learning will also be discussed. All instructors teach analytical chemistry and/or general chemistry at institutions ranging from large public universities to small or mid-sized primarily undergraduate institutions that serve significant numbers of low-income or first-generation college students. The strategies for remote active learning presented in this article were used in classes with enrollments between 20 and 50 students.

Facilitating active learning and group work in a remote setting

Freeman defines active learning as “engaging students in the process of learning through activities and/or discussion in class, as opposed to passively listening to an expert. It emphasizes higher-order thinking and often involves group work.” [6] However, an active learning class session does not consist entirely of small-group discussion. The role of the instructor in facilitating an effective learning environment is extremely important. The instructor often provides “mini” lectures to explain difficult concepts and when students present their group’s answer to the whole class, the instructor identifies and corrects misconceptions, elaborates more deeply on the topic, or poses additional questions.

A major challenge for instructors is to adapt methods used for in person active learning to the online environment. A common method of including group discussion in a virtual class is to use video conferencing services such as Zoom to divide participants in breakout rooms. However, there are some major differences between facilitating active learning in person and online. Student discussions in Zoom breakout rooms are less efficient than in person. In the classroom, an

instructor can pass out a worksheet and students can arrange their seating to easily share their answers both visually and orally. It is much more difficult for online students to display their solutions to other group members and conversation moves at a slower pace. Furthermore, it is challenging for the instructor to assess the understanding of the whole class as students work on the activities because the instructor can only interact with one group at a time. It is also more difficult for the instructor to make a quick clarification or provide a helpful hint when students are working in breakout rooms because it takes time to post an announcement and/or bring everyone back together in the main room. Therefore, students must have better advance preparation to tackle the group activity during virtual class than during an in-person class. Herein, we provide a description of different strategies and technological tools that enable us to implement effective virtual active learning.

General chemistry courses

A 25-student general chemistry class at Indiana University (IU) used a hybrid format with some students attending in person wearing masks and socially distanced and other students joining online. On a typical day, there were 15 students in person and 10 students joining the class using Zoom. The synchronous classes consisted of short lessons in combination with small-group problem-solving. Short lectures (5–10 min) were given on a topic and then students answered questions individually or in groups. Learning Catalytics, a personal response tool, was used to assess the understanding of the whole class. The polling feature in Zoom can also be used to deliver multiple choice questions or the instructor can display a question and students can submit text or numerical answers using the chat feature. Challenging questions frequently result in significant numbers of students with incorrect responses, which allows the instructor to identify misconceptions and provide useful feedback. When there is a wide distribution of responses, students are placed into groups to discuss the problem. Once the discussion is finished, one group is called upon to explain their answer. The student who speaks for each group is selected based on a simple question posed at the start of class such as “Who has the most pets?” These questions not only identify the speaker but also help students get to know one another. The instructor transcribes the answer on the screen and expands on the student’s explanation as needed. Ultimately, the correct solution is displayed for the whole class. Small-group discussion is most effective when students are comfortable with other group members, so it is recommended to only change the composition of groups once or twice during term. Students received a class participation score, which resulted in high attendance over the term.

A 50-student general chemistry course at Eastern Oregon University (EOU) used both synchronous and asynchronous delivery with Zoom synchronous sessions available four times per week. A Learning Management System (LMS) served as a repository for all assignments and resources, including short videos pre-recorded by the instructor on a specific topic that were assigned prior to the “live” session. Each session opened with a brief recap of the previous topic and ample time was devoted to answering questions about the material in general or specific assignments and to addressing misconceptions identified from prior activities. Each session also included an active learning exercise made available either through shared Google Docs¹ or through the polling feature of a commercial online homework assignment that students could access simultaneously. The latter could be set up with different question formats and provided instant feedback. Students were divided in small groups through the Zoom breakout room feature and asked to discuss and complete their activity. The instructor and students used a combination of video, chat feature, white board, or Google documents to interact (Fig. 1). Usually, an activity was limited to one or two questions to ensure that it could be completed in the allotted time. The instructor rotated through breakout rooms to facilitate discussion or provide assistance on a specific concept or calculation. At the conclusion of each activity, two or three groups were asked to share their findings for the instructor or other groups to provide feedback. Group activities were collected and graded.

Analytical chemistry courses

In a 33-student quantitative analysis course at California State University-Chico (CSUC), students met once per week for synchronous active learning sessions and had two asynchronous class days. On asynchronous days, students watched three or four videos created by the instructor. Each video was 15–20 minutes long and were a mixture of theory and calculation problems. After watching the videos, the students completed a worksheet created by the instructor or adapted from the “Active Learning” section of the Analytical Sciences Digital Library [16]. Students were encouraged to work together to complete these worksheets. Students were awarded points for completion of the worksheets; the sum total of their worksheet points equaled one in-class exam.

In the virtual environment, shared documents that allow for real-time editing and collaboration (e.g., Google Docs, Sheets, Slides, and Jamboard) worked well as a replacement for whiteboards/chalkboards for facilitating group work,

¹ All of these tools are available through the Google suite; instructors should use caution when employing this suite of tools if they have students participating from countries where Google is blocked.

Fig. 1 Eastern Oregon University students use the Zoom chat feature during synchronous small-group class activity in a general chemistry course

Group activity 4 - Chemical Equilibrium
Learning outcomes

Determine the constant of equilibrium expression for heterogeneous systems.

For the system: $\text{CaO}(\text{s}) + \text{CO}_2(\text{g}) \rightleftharpoons \text{CaCO}_3(\text{s})$

The equilibrium constant expression is:

A. $[\text{CaCO}_3]/[\text{CaO}] [\text{CO}_2]$
B. $1/[\text{CaO}] [\text{CO}_2]$
C. $[\text{CO}_2]$
D. $1/[\text{CO}_2]$

Chat Messages

Student 1 01:26:52
I think we need to consider the labels

Student 2 01:27:01
So all non-gasses are represented as 1?

Student 2 01:27:15
Or just solids?

Student 3 01:28:01
Solids or liquids that are in the numerator are represented as 1. Also in the denominator.

Student 1 01:28:31
Is this a K_p or K_c ?

Student 3 01:28:56
It is not specified but aren't the brackets like concentration?

providing a place for students to write out their work as well as serving as an alternate mode of communication between the students and the instructor. During synchronous class periods, students accessed an editable student response slide deck. Each synchronous class began with student learning outcomes and a few slides of traditional lecture from a separate slide deck. Then, students were assigned to groups of 4–5 students in breakout rooms. Each breakout room had an assigned recorder and a reporter. In the student response slide deck, there were as many copies of each individual problem slide as there were breakout rooms. Collaborative groups of students in their breakout rooms were verbally given a set amount of time to complete each problem, and time warnings were broadcast using the announcement functionality of Zoom. Problems included calculations, explanations, sorting, labeling, and vocabulary activities. Students could choose to contribute verbally to their breakout room members, edit the slide directly, or use the chat feature in Zoom. The instructor can visit a breakout room to provide verbal feedback or simultaneously monitor the progress of all groups by viewing and adding suggestions to the slides. After all students were brought back to the main session, 2–3 groups reported out to the whole class. Once student questions were resolved, another cycle of lecture slides and new breakout room work was initiated.

Using the structure of group work on shared documents maintained much of the look, feel, and student interaction of a traditional in-person semester. Both the small-group and whole-class discussions were in general as productive as previous in-person meetings. The students reported that they appreciated the chance to collaborate and have some normal social interactions while completing group work. In a course survey, students stated the discussions were helpful for clarifying misunderstandings.

In a 20-student analytical chemistry course at The College of New Jersey (TCNJ), students worked in small

groups on activities during regularly scheduled class sessions. Pre-class assignments were used to prepare students for participation in group activities during synchronous class meetings. These assignments varied—sometimes, students were assigned a short video or reading with questions to answer, while other times they might be asked to respond to a discussion post. The pre-class assignments were typically graded for completion but were also scanned for common misconceptions that could be addressed during class. During the synchronous class time, questions/misconceptions from the pre-class assignment would be addressed before students were split into assigned breakout rooms to work on the in-class assignment. These activities included more structure and guiding questions compared to those in face-to-face classes, allowing students to work more independently as the instructor rotated between breakout groups. Similar to the class at CSUC, real-time written collaboration was possible via the use of a shared document provided in advance by the instructor (Fig. 2). A post-class activity was often assigned to provide students with additional opportunities for practice and/or higher-level application, often in the form of a formative assessment such as a short quiz or discussion prompt. A rubric built into the LMS allowed for expeditious grading. Students generally reported appreciating the structured nature of the course and suggested keeping pre-class assignments when we return to in-person teaching.

Barriers to student engagement in online courses

Remote learning requires the university community to re-evaluate issues of equity and accessibility which are, in

Fig. 2 TCNJ students debate their response to an exam question while the instructor annotates their discussion points in a shared document in real time

GROUP 2

Explain what **type of error** would be introduced and how you might be able to correct for it experimentally:

a variety of food samples have varied viscosities after sample prep; the sensitivity of the device is heavily dependent on flow rate

*This error would be **random**, as it is dependent on the sample itself and not the method you are analyzing the sample with. In other words, the sample is not replicable. In order to correct this, a **standard addition** could be done, where a standard is added directly to each of the food samples. The purpose of this standard would be to allow the viscosities/flow rates to be more consistent, and would thus allow the sensitivities to be more similar for all the different samples.*

Anthony

Instructor
2:57 PM Dec 11

systematic? this would shift results in same way each time. Issue w/ experimental design.

Instructor
2:59 PM Dec 11

random error would have equal chance of + or - impact on results

part, mitigated when students are physically present in the same room. In the online environment, differences are exacerbated by limited technological infrastructure, personal access to a computer and the Internet, or even the availability of quiet space to study. Students completing courses at home often share a space and Internet connection with other family members who are also learning or working remotely. Furthermore, time zone differences, power outages due to inclement weather, and other personal situations prevent students from attending live course meetings.

Recent surveys conducted in Fall 2020 provide more detail about the extent of these issues. The National Survey of Public Engagement (NSSE) Pulse was administered at Indiana University to collect information about quality of interactions, campus support, and challenges to learning during the pandemic [17]. Data from nearly 4000 students show that 15% of students do not have sufficient Internet service to participate in their courses, 7% do not have sufficient hardware, and 27% lack access to study spaces that are sufficient for their needs. Eastern Oregon University also released the results from a survey where approximately 400 respondents identified challenges faced by students and interventions to better support student well-being and ensure academic success [18]. When asked to rate their participation during Zoom sessions as compared to in-person class sessions, 33% of respondents indicated that they are less willing to provide answers to instructor's questions, 30% are less willing to participate in class discussions, and 36% are less willing to ask questions of the instructor. Furthermore, 39% experienced issues that affected their ability to fully participate in classrooms, citing health issues, essential worker responsibilities, limited access to Internet connectivity or equipment, food and/or financial insecurity, parental responsibilities, and mental health concerns as reasons. Understanding the nature of barriers to remote learning and the support that students need for success is critical in designing and implementing an effective virtual course. Table 1 summarizes challenges to online student learning and options for interventions.

Classroom interventions to alleviate students' challenges in online classes

During remote learning, modifications to course structure are necessary to provide a more equitable educational experience and enable students to actively participate in the course. Some interventions that the authors used to alleviate problems include:

- Increased course structure with low-stakes assignments
- Asynchronous and synchronous components
- Flexible participation methods and deadlines
- Alternative assessment formats

Increased course structure with low-stakes assignments

Graded preparatory assignments, student discussion of activities during class sessions, and graded review assignments are ways to increase the structure of a course [19]. Several studies found that increasing course structure improved performance for all student populations, but worked disproportionately well for minorities and first-generation students [8, 19–21]. In a course with high structure, students completed assigned readings more frequently, spent more time studying, and felt an increased sense of community [20]. All authors found that a moderate to high course structure, which included active learning, was a particularly useful approach in online courses where students can find it difficult to stay on track and connect with other students. Pre-class assignments, in-class group work, and homework are low-stakes assignments that were used in all of our courses and contributed from 10 to 35% of the total course grade.

Asynchronous and synchronous components

During remote instruction, asynchronous content delivery is necessary to ensure student access to course materials.

Table 1 Challenges to student learning in the remote environment and some interventions

Students' self-reported challenges	Interventions
Limited Internet bandwidth/poor connectivity	Access to course materials asynchronously
Lack of quiet study space	Flexible assignment deadlines
Different time zone	Extended testing time
	Alternative communication methods
Insufficient hardware	Students' surveys to determine available technologies
	Campus technology assistance programs (laptop loan program, local and regional Wi-Fi hotspots)
Limited interaction with peers	Small-group collaborative learning (synchronous or asynchronous)
	Assigned study groups
	Peer reviewed assignments
Limited interaction with instructors	Additional office hours at convenient times for students (e.g., right after class)
	Mandatory check-ins during class or laboratory meeting times
Personal challenges (financial/food insecurity, increased family responsibilities, mental health concerns)	Information in course management system related to campus and community support; local food banks, health services, counseling services

However, synchronous activities provide the types of interactions that deepen learning and improve important communication skills. All authors recorded synchronous class sessions for absent students to view on their own time. Jill Robinson (IU) and Rebecca Hunter (TCNJ) had nearly 100% attendance in their remote courses and found they did not have to make additional accommodations for absences. In contrast, some courses may have significant numbers of students who cannot regularly attend due to time zone differences, family responsibilities, regular disruptions to Internet service, and lack of sufficient hardware. Anna Cavinato (EOU) discovered many students were not able to attend her synchronous courses and lived in rural areas with limited Internet bandwidths. She found that short, single-topic videos of 10–15 minutes were useful for on demand viewing by her students. Lisa Ott (CSUC) addressed barriers to student attendance by having both asynchronous and synchronous class periods each week. This approach can relieve the burden that synchronicity places on student home life, while providing weekly opportunities for interaction with their instructor and peers.

Flexible participation methods and deadlines

All authors scheduled additional virtual office hours to create more opportunities for assistance and interaction with the instructor. In addition, Anna Cavinato (EOU) remedied the problem of students no longer being able to join scheduled class sessions by allowing students to sign up for alternate time slots to complete group assignments. Students received asynchronous feedback upon submission of their work through a shared document or, when possible, received individual or group assistance during office hours.

To accommodate different home situations and respect privacy, students in the analytical course at TCNJ were polled to

indicate their preference for group work format: (1) active—camera and microphones almost always on with active discussion; (2) quiet—favor a mix of independent work and discussion with others but prefer not to continuously use camera and/or microphone; (3) solo—strong preference to work on their own. In this course, only 35% of students preferred active group work, and even fewer (15%) opted for solo work. The remaining 50% of students preferred a hybrid (the “quiet” group). Pre-assigned breakout rooms were created based on their preferences, with 3–4 students assigned to each group. Students were provided with a shared document to record their work. Each group found their own way to work effectively during breakout sessions and students from all groups (including the solo students) readily contributed to the shared document and whole-class discussions.

Although assignment deadlines are necessary to keep students on track, all authors granted some flexibility in due dates. One simple strategy is to program the LMS to drop the lowest score in a category (such as homework or quizzes), thus letting students miss or turn in an assignment late without burdening the instructor. Due dates can also be adjusted for individual students on a case-by-case basis.

Alternative assessment formats

Technology issues can increase anxiety and reduce the amount of time students have to complete online exams, thus negatively impacting their scores. Additionally, live proctoring of exams is often not feasible due to financial limitations, technology requirements, and privacy concerns. Therefore, methods to minimize the temptation of academic dishonesty should be considered. Often the root cause of cheating is educational environments that create anxiety through high-stakes exams with limited time [22, 23]. One

alternative is open-resource exams that students can complete over an extended time period.

Several authors administered open-resource assessments that were available over a 12–24-h time period and allowed for extended time; such as 1.5–2 times longer than a typical exam. The authors defined clear rules for behaviors and the use of resources in exam instructions and students were required to sign a pledge that they would abide by these rules or suffer academic dishonesty penalties. Students indicated they were less stressed, had adequate time, and felt more confident they were able to demonstrate their knowledge on open-resource exams than on timed exams administered using unfamiliar technology. At CSUC, exams were made available through the campus LMS. Students downloaded a copy of the exam and were required to show all work in their own handwriting when they uploaded the completed exam. Students were also allowed to submit Excel spreadsheets for their calculations. At TCNJ, analytical chemistry students had access to unlimited resources during exams, as long as the work submitted was their own and sources other than course notes were cited. The questions combined multiple concepts and necessitated higher-order thinking, often requiring an essay-style justification of their answer. The complexity of these types of questions makes it unlikely to simply search for the answer online. The unique answers also enable the instructor to determine if students collaborated with one another. This, combined with a collaborative discussion component, made it clear which students truly understood the content.

A collaborative approach is often used to solve scientific problems and students should develop the skills needed to work productively with others. Collaborative final exams have been discussed in this column previously [24], but we will describe using team exams and quizzes more broadly over the entire term. In the analytical chemistry course at TCNJ, students completed open-resource exams independently over a 36-h period—this score constituted 60% of their overall grade. The inclusion of questions with more than one “correct” approach or answer was particularly important for facilitating robust discussion during the group component of the exam, which occurred during a scheduled class meeting. These more open-ended questions require students to provide a solution along with a justification. Examples of such questions can be seen in Fig. 2 and include explaining how to redesign an experiment to account for a specific type of error, or how to improve the resolution between two chromatographic peaks. Students were split into randomly assigned breakout groups to work on their assigned question(s) for 20–30 min. Groups typed their responses into a provided Google slide deck that contained each question and the corresponding group assignment. Following the discussion period, each group presented their proposed answers to the whole class. All students were then given an opportunity to provide their input, ask questions, or propose an alternative solution.

As each student had also completed the exam independently (and grades were at stake), many students would chime in if they were unsure about the proposed answer, including those who were typically quieter during normal class meetings. This was an excellent opportunity for the students to work out misunderstandings amongst themselves and students frequently realized mistakes they had made during this process. During this discussion, the instructor would annotate the slides with edits, new ideas, and solutions presented, but provide no direct feedback. The final group submission had to be agreed upon by the entire class (confirmed using the “thumbs up” emoji in Zoom). The instructor provided immediate feedback on the final answer, and this consensus answer was used as the group score (40% of the overall grade). Across three semester exams and a final, the addition of the collaborative component resulted in a 5–6 percentage point increase in exam scores compared to the individual component alone. More importantly, the group component contributed to their understanding of the material. Students agreed the exam format and immediate feedback allowed them to correct misconceptions and think more deeply about new concepts compared to more traditional exams.

General chemistry students at IU took team-based quizzes using Learning Catalytics, an interactive student response tool. There are 12 question types available, but the most commonly used styles were multiple choice, many choice, numerical, matching, sorting, and choosing a region on an image. The Learning Catalytics software was bundled with the course text, but can be purchased separately for \$12. A team-based quiz can also be implemented in a low-tech way or using the quiz tools in a LMS. One benefit of collaborative assessments is the strong camaraderie that develops between students in a group. Students formed groups of 3–4 either in person (wearing masks and socially distanced) or online in Zoom breakout rooms (Fig. 3). The first task was to decide on a team name which got the creative juices flowing and led to a fun atmosphere as names such as “Pray for us” and “The Kinetics Crusaders” appeared on the screen. Students first answered quiz questions individually before discussing answers with their group. The individual portion was worth 25% of the grade and the group portion worth 75%. The group portion was weighted more heavily because challenging questions were included and the quiz was used as a learning tool, not an individual assessment. Only one answer can be submitted for the team which leads to very lively discussion. Students gain practice making scientific arguments and all team members contribute. After the first quiz, the more reserved students realized that sometimes the loudest speaker did have the right solution and, in the future, they lobbied more strongly for their own answer. Once the team submitted their response, the program provided feedback about whether they were right or wrong and revised answers could be resubmitted with a point deduction. Students often would release whoops of joy when

Fig. 3 Students in class wrote out their answers to group quiz questions on small whiteboards so they could more effectively discuss answers from a distance. The whiteboard could also be held up to a computer camera to communicate with a classmate joining the team using Zoom (Courtesy of Erid Rudd-Indiana University)

their team answer was correct! The solutions to quiz problems were discussed at the end class. Another benefit of regular collaborative assessments is that there is more at stake than group work in a regular class session. Students reviewed the material before coming to class and gave a significantly higher level of effort than on a normal class day. Overall, the group quizzes were a terrific learning tool and provided a way to form bonds between classmates.

Conclusion

Understanding the challenges students encounter in the online learning environment helps inform strategies and interventions to create an equitable learning experience. This is particularly important for student populations at higher risk such as rural, first-generation, and/or low-income students. Successful strategies include using active learning, incorporating grading schemes with low-stakes assignments, providing synchronous and asynchronous access to course components, and allowing more flexible deadlines for tests and assignments. The extensive use of group work, enabled by various technologies, increases student engagement and creates interactive virtual class environments that are conducive to learning. Students valued the collaborations as a way not only to increase their understanding of course materials but also to foster connections with classmates.

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Declarations

Conflict of interest The authors declare no competing interests.

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