Abstract

As a result of the COVID-19 pandemic, many instructors were forced to adjust from in-person to emergency remote teaching; however, classroom observation protocols, like the Classroom Observation Protocol for Undergraduate STEM (COPUS), have only been developed and validated for in-person instruction. Therefore, we developed and validated an adapted version of COPUS, called Online COPUS (O-COPUS), to measure teaching and learning practices during online synchronous instruction. We collected COPUS and O-COPUS data from 35 STEM instructors teaching via in-person and online synchronous instruction at a research-intensive, minority-serving institution (MSI). By identifying emergent codes from live observations and using an exploratory coding process, we adjusted six instructor and six student COPUS code descriptions for O-COPUS. As we prepare for teaching in the future, it is important to have formative assessment tools, like classroom observation protocols, designed for all course formats to be able to measure and improve pedagogical practices in college STEM classrooms.

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Breakout Rooms, Polling, and Chat, Oh COPUS! The Adaptation of COPUS for Online Synchronous Learning

Instructors and the teaching practices they employ play a critical role in improving student learning in science, technology, engineering, and mathematics (STEM) courses (Smith et al., 2013b). Active learning is an evidence-based teaching practice which requires students to engage cognitively and meaningfully with the course materials (Bonwell & Eison, 1991; Chi & Wylie, 2014). There are many benefits associated with the implementation of active learning (Chickering & Gamson, 1987; Crouch & Mazur, 2001; Freeman et al., 2014), such as improved student attitudes (Armbruster et al., 2009) and retention of course material (Pérez-Sabater et al., 2011; Schwartz et al., 2011; Vanags et al., 2013) as they are practices that improve learning for all students, particularly persons excluded because of their ethnicity or race (Asai, 2020). Recently, Denaro et al. (2021) noted a national focus on implementing active learning to improve the quality of STEM education promoted by, among others, the National Research Council (2012), Olson and Riordan (2012), and Laursen (2019). Therefore, shifting large numbers of STEM faculty to include even small amounts of active learning in their teaching may effectively educate far more students and raise retention of undergraduate STEM students (Owens et al., 2017).

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Ongoing formative assessment is a key instructional practice in student-centered learning environments (MacIsaac, 2019; Offerdahl et al., 2018; Rosenberg et al., 2018). Historically, undergraduate teaching has been predominantly transmissionist in nature with the goal of conveying information to students (Barr & Tagg, 1995). However, with the benefits associated with active learning, it is imperative that STEM instructors consider how they can effectively implement student-centered practices in all formats of their classrooms. Therefore, an array of tools have been developed over the past two decades to measure enacted teaching practices in the in-person context, especially in STEM courses (Eddy et al., 2015; Owens et al., 2017; Sawada et al., 2002; Smith et al., 2013b). To name a few, the Practical Observation Rubric To Assess Active Learning (PORTAAL) (Eddy et al., 2015), the Decibel Analysis for Research in Teaching (DART) (Owens et al., 2017), the Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002), and the Classroom Observation Protocol for Undergraduate STEM (COPUS) (Smith et al., 2013b) provide a way of collecting unbiased data by a trained third-party or an application like the Generalized Observation and Reflection Platform (GORP) (Tomkin et al., 2019; University of California Davis, 2018; van der Lans, 2018). Out of all of these classroom observation protocols, COPUS has commonly been used to examine instructor and student behaviors using 25 codes occurring during in-person teaching in STEM classrooms (Smith et al., 2013b). Table 1 offers a description of the COPUS codes: 12 instructor behaviors, such as *lecturing* and *moving and guiding*, and 13 student behaviors, such as *listening* and *asking questions*.

For faculty professional development and education research efforts, COPUS codes have been characterized as traditional lecturing or active learning through various descriptive methods or the presence of various COPUS codes among different population of instructors (Akiha et al., 2018; Kranzfelder, Lo, et al., 2019; Lewin et al., 2016; Reisner et al., 2020; Smith et al., 2013b). For example, Akiha et al. (2018) calculated the frequency of various COPUS codes to analyze the differences in how instructors implemented traditional lecturing and active learning in middle school, high school, first-year university, and advanced university STEM classes. Results showed that students in middle school and high school participated in more active learning activities, such as group work, than first-year or advanced university STEM classes. Furthermore, middle school and high school instructors were also more active in the classroom, such as moving and guiding their students in active learning tasks, than first-year or university classes (Akiha et al., 2018). Also, analyses have been conducted through statistical methods to describe how instructors' teaching practices are related across COPUS codes (Commeford et al., 2022; Denaro et al., 2021; Stains et al., 2018; Tomkin et al., 2019). Tomkin et al. (2019) used regression models to assess the differences in teaching practices between instructors who were involved in a community of practice (CoP) (Wenger, 1996) versus those that were not. They found that instructors who were a part of a CoP implemented more active learning practices compared to non-CoP instructors (Tomkin et al., 2019). Additionally, COPUS data have been used in combination with other tools, such as the Classroom Discourse Observation Protocol (CDOP) (Alkhouri et al., 2021; Kranzfelder, Bankers-Fulbright, et al., 2019) and Instructor Talk (Lane et al., 2021; Seidel et al., 2015). Lane et al. (2021) examined what instructors teaching STEM courses do on their first day of class. They paired COPUS and Instructor Talk data to suggest that negatively phrased Instructor Talk was less common among instructors who used student-centered teaching practices (Lane et al., 2021). As a result, COPUS data have been analyzed and applied in a variety of ways to characterize STEM classroom behaviors.

COPUS codes have been used to analyze differences in traditional lecturing and active learning in STEM classrooms, and have been applied in various ways to characterize STEM classroom behaviors, including during the sudden shift to emergency remote teaching during the COVID-19 pandemic.

As a result of the COVID-19 pandemic, many instructors were forced to transition their course modality rapidly from in-person to online instruction. The sudden shift was constituted as emergency remote teaching (ERT) (Hodges et al., 2020). In contrast to traditional online teaching and learning, which has been studied and implemented for decades (e.g., Ally, 2004; Darby & Lang, 2019; Means et al., 2014; Nilson & Goodson, 2021), ERT is a temporary shift from in-person, blended, or hybrid courses to fully online teaching due to crisis circumstances. It provided access to online instruction and instructional supports in a manner that was quick to set-up, reliable (Hodges et al., 2020), and required instructors who were mostly inexperienced with online teaching to become familiar with new teaching tools and techniques including asynchronous and synchronous formats (Giesbers et al., 2014; Nilson & Goodson, 2021; Skylar, 2009). Some instructors choose to implement an asynchronous format (e.g., recorded lectures, discussion boards, and at-home assignments) if they were concerned about their own or their students' abilities to attend and participate in live online lectures (Lemke, 2022; Van Heuvelen et al., 2020). In contrast, instructors more often adopted a synchronous format (e.g., videoconference call or live online lectures) as this can encourage student-instructor interactions and group work (Heiss & Oxley, 2021;

Table 1
COPUS Coding Scheme

	COPUS Codes	COPUS Code Descriptions
Instructor Doing	Lecturing (Lec)	Lecturing (presenting content, deriving mathematical results, presenting a problem solution, etc.)
	Real-time Writing (RtW)	Realtime writing on board, doc. projector, etc. (often checked off with Lec)
	Demo or Video (D/V)	Showing or conducting a demo, experiment, simulation, video, or animation
	Follow-up (Fup)	Follow-up/feedback on clicker question or activity to entire class
	Posing a question (PQ)	Posing non-clicker question to students (nonrhetorical)
	Clicker question (CQ)	Asking a clicker question (mark the entire time the instructor is using a clicker question, not just when first asked
	Answering questions (AnQ)	Listening to and answering student questions with the entire class listening
	Moving and guiding (MG)	Moving through class guiding ongoing student work during active learning tasks
	One on one (1o1)	One on one extended discussion with one or a few individuals, not paying attention to the rest of the class
	Administration (Adm)	Administration (assign homework, return tests, etc.)
Students Doing	Group Clicker Question (CG)	Discuss clicker question in groups of 2 or more students
	Group Worksheet (WG)	Working in groups on worksheet activity
	Other Group Work (OG)	Other assigned group activity, such as responding to instructor question
	Answering questions (AnQ)	Student answering a question posed by the instructor with rest of class listening
	Student Question (SQ)	Student asks question
	Whole class discussion (WC)	Engaged in whole class discussion by offering explanations, opinion, judgment, etc. to whole class, often facilitated by instructor
	Prediction (Prd)	Making a prediction about the outcome of demo or experiment
	Student Presentation (SP)	Presentation by student(s)
	Test or Quiz (TQ)	Test or quiz
	Waiting (W)	Waiting (instructor late, working on fixing AV problems, instructor otherwise occupied, etc.)
	Other (O)	Other – explain in comments

Note: COPUS codes and code descriptions from Smith et al. (2013a).

Lang, 2020; Van Heuvelen et al., 2020). In the systematic review of research on ERT in higher education before the pandemic, text-based tools used for asynchronous instruction (e.g., discussion forums) were most often used by instructors (Bond et al., 2020). During the pandemic, they found that there was a much higher use of synchronous collaboration tools, especially video conferencing platforms like Zoom, Teams, and Google Meet (Bond et al., 2021). Nevertheless, teaching in a synchronous format does not guarantee student participation; for example, Reinholz et al. (2020) found an overall decrease in student participation in biology classrooms as the class transitioned from in-person to synchronous instruction during ERT. However, the transition from an in-person to online synchronous instruction mid-course presented many challenges, including maintaining active student engagement (Giordano & Christopher, 2020).

During the COVID-19 pandemic, there have been a few studies that have documented teacher and student behaviors because of the shift to online synchronous instruction during ERT. Some instructors were not able to implement the best active learning strategies for online learning (Youmans, 2020), but others approached this challenge with creativity leading to opportunities for classroom pedagogical innovations including adaptations of student-centered activities. To recreate activities that were administered before ERT, Tan et al. (2020) utilized the Zoom breakout room function which creates small videocall rooms within the main virtual meeting, as well as Padlet, a virtual whiteboard. In pre-assigned breakout rooms, students would have discussions facilitated by an instructor or teaching assistant who were present in each breakout room. By asking students to turn their microphone functions on, groups were highly engaged in discussions. Singhal (2020) also utilized breakout rooms when assigning group active learning activities and moved between groups as they worked collaboratively. Tan et al. (2020) also utilized Poll Everywhere, an online tool for live polling to engage students actively during online synchronous instruction. Similarly, Christianson (2020) utilized Socrative, another online tool for live polling, to assign their students group quizzes at the beginning of class. During the administration of the quiz, students used Microsoft Teams to engage in group discussion on the quiz questions. Tan et al. (2020) found that the Zoom chat function, a messaging system within the video call room that allows participants to send messages to the group or direct messages to each other, was valuable to maintain interactions among faculty, teaching assistants, and undergraduates in the course. Researchers also found that students in the course seemed to respond to more questions and participate more in the chat compared to in-person discussions. In a large-enrollment biochemistry course, Dingwall (2020) designed templates for metabolic pathways that students could actively fill out during lecture. Students agreed that these templates were useful in online synchronous instruction because it allowed them to engage in lecture material rather than passively listen to their instructor. Therefore, while there have been studies documenting what classroom technology tools were successful in implementing active learning strategies during ERT (Christianson, 2020; Dingwall, 2020; Singhal, 2020; Tan et al., 2020), studies have not been conclusive about how to document the specific teaching and learning practices that have implemented in online synchronous instruction. More specifically, formative assessment tools are needed to measure these practices in a reliable and valid manner.

Shift to online synchronous instruction during ERT led to innovative classroom pedagogical practices, including the use of breakout rooms, virtual whiteboards, and live polling tools to engage students actively, but there is a need for reliable assessment tools to measure these practices.

During ERT, instructors, institutional assessment programs, and biology education researchers faced a problem of not having reliable, validated classroom observation tools that could be easily implemented online by trained observers to measure teaching and learning behaviors. As described above, Smith et al. (2013b) developed and validated COPUS for in-person instruction, so we responded to the need to adjust some COPUS code descriptions to document teaching and learning practices more efficiently for online synchronous instruction. Although adjusting the original COPUS code descriptions to fit online synchronous instruction may seem like a seamless transition, many universities stopped conducting COPUS observations during ERT due to its complexities. For instance, UC Irvine put COPUS observations on hold because they "were lacking the resources to validate a novel observation protocol in the face of the numerous other COVID-19-related challenges" (personal communication with Brian Sato, 07/20/2021). Additionally, UC San Diego commented: "We had trained undergrads to do the observations and didn't think we could ask them on the fly to adjust things" (personal communication with Melinda Owens, 07/20/2021). Some institutions utilized COPUS as an assessment tool to support instructors while transitioning to online synchronous instruction (Clark et al., 2020); however, they did not validate the tool for this new study context (i.e., ERT).

Study goal and objectives

Therefore, out of necessity, the goal of this study was to adjust the original COPUS code descriptions to document online synchronous teaching and learning practices as well as online functions that instructors may incorporate into their future teaching practices. This adaptation was not intended to capture asynchronous teaching and learning practices as the original COPUS was developed around live in-person class sessions. By adapting COPUS for online synchronous instruction, instructors will have the ability to make comparisons between past, present, and future teaching and learning practices as they move to other instructional modalities, such as in-person, hybrid, or hybrid-flexible (HyFlex) (Beatty, 2019). The objectives for this case study were to:

In adapting COPUS for online synchronous instruction, instructors will have the ability to make comparisons between past, present, and future teaching and learning practices as they move to other instructional modalities, such as in-person, hybrid, or hybrid-flexible.

1. Adapt and validate COPUS for online synchronous instruction (O-COPUS) and effectively train observers to collect reliable COPUS and O-COPUS data.
2. Create an O-COPUS codebook that captures commonly observed online teaching and learning practices.
3. Showcase sample data that instructors or researchers might obtain from original COPUS compared to the adapted O-COPUS protocol.

Case Study

This study was approved by UC Merced's Institutional Review Board, and all participating instructors provided informed consent to anonymously participate in the study (Protocol ID UCM2020-3).

Participants and instructional context

For this study, we drew on previously collected classroom data from 40 undergraduate and graduate STEM courses taught by 35 instructors at the University of California, Merced (UC Merced), a research-intensive, minority-serving institution (MSI) in the western United States. This larger ongoing research project was funded by two research grants: the Howard Hughes Medical Institute Inclusive Excellence (HHMI IE) awarded to the biology program and the National Science Foundation Hispanic Serving Institution (NSF I) awarded to the chemistry and biochemistry department with the goal of understanding, documenting, planning, and enacting meaningful initiatives to improve teaching and student learning at UC Merced. As part of that project, we collected data from STEM instructors each semester before the transition to ERT (fall 2018 through spring 2020), during the transition to ERT (spring 2020), and/or during the continuation of ERT (fall 2020 and spring 2021) (Table 2). We chose instructors for that larger project who had: 1) taught either a lower or upper division undergraduate or graduate STEM course; 2) taught a lecture course (excluding laboratory, discussion, or seminar courses); and 3) either taught in-person or via online synchronous instruction (excluding asynchronous instruction). Lund et al. (2015) found that at least three successive classroom observations are necessary to characterize adequately an instructor's teaching practices; therefore, we conducted at least three classroom observations per instructor.

Descriptive information about the instructors and courses included in this study can be found in Table 2. Instructors taught mainly lower division undergraduate courses from a variety of STEM disciplines with the majority being in biology or chemistry. All three instructor types from our institution (tenure-track research faculty, tenure-track teaching faculty, and non-tenure track contingent faculty, i.e., lecturers) were observed with the majority being tenure-track research faculty. Course class sizes ranged from four to 292 students with a mean of 110 students. One of the authors was also one of the participating instructors; we did not collect or analyze the data.

Table 2
Instructor and course demographics

	In-person		Online	
Characteristics	Fall 2018 – Spring 2020	Spring 2020	Fall 2020	Spring 2021
Discipline				
Biology	16	9	6	7
Chemistry	9	1	5	5
Mathematics	4	4	0	0
Physics	4	2	0	0
Engineering	2	0	0	0
Instructor type				
Research faculty	14	8	5	5
Teaching faculty	8	4	2	3
Lecturers	13	4	4	4
Course Size				
Small (≤60 students)	12	6	1	1
Medium (61-100 students)	3	3	0	0
Large (>101 students)	20	7	10	11
Class level				
Lower division	25	9	10	10
Upper division	7	5	1	1
Graduate	3	2	0	0
Total	**35**	**16**	**11**	**12**

Note: Classroom observation data were collected from 40 STEM courses taught by 35 different instructors. During the transition and continuation of emergency remote teaching, some instructors from our original study did not continue their participation.

Methods

Students Assessing Teaching and Learning (SATAL)

Since 2009, the undergraduate interns from UC Merced's Students Assessing Teaching and Learning (SATAL) collaborate with faculty who are focused on pedagogical and curricular exploration and have the desire to understand their students' experiences and perspectives in order to inform classroom practices (Signorini & Pohan, 2019). To accomplish this, SATAL implements a wide range of assessment tools for gathering student perspectives, including classroom interviews, surveys, and COPUS. SATAL interns work with faculty to provide assessment results and feedback to improve students' experience in their class. Since 2018, the undergraduate interns from the SATAL program have partnered with faculty to conduct multiple COPUS research projects for different purposes. Therefore, the adaption of COPUS during ERT came naturally to the SATAL program as they continued to collaborate with faculty during ERT on COPUS research projects.

Undergraduate interns from UC Merced's SATAL program play a vital role in implementing a wide range of assessment tools, including COPUS, to improve classroom practices and gather student perspectives.

COPUS Data Collection

During in-person COPUS observations, SATAL interns followed the COPUS codebook in Smith et al. (2013b) to document instructor and student behaviors in 2-minute intervals throughout the duration of the class session. We created a COPUS Frequently Asked Questions (FAQs) to describe in further detail whom we code (leading instructor, co-instructor, or teaching assistant), what behaviors we categorize under different COPUS codes, and what codes we pair together when a particular behavior occurs (File S1, S2).

We refined the codes descriptions using focused coding and then we reached coder agreement through group consensus.

COPUS Reliability

We trained 15 SATAL interns for four hours between two training sessions for these in-person COPUS observations. Each of the two sessions consisted of pre- and post-activities as well as a 45-minute coding activity which utilized in-person lecture recordings by instructors of our home institution. These training sessions followed an adapted and extended version of the COPUS training in Smith et al. (2013b) (File S3). To quantify the degree of agreement between observers, we calculated inter-rater reliability (IRR) using Fleiss' Kappa. Landis and Koch (1977) suggested the following interpretations of Fleiss' Kappa (κ): 0.0-0.20 poor to slight agreement, 0.21-0.40 fair agreement, 0.41-0.60 moderate agreement, 0.61-0.80 substantial agreement, and 0.81-1.0 almost perfect agreement. Before conducting in-person observations, we trained observers until we reached moderate agreement (κ = 0.56,7 95% CI: 0.55-0.56) (File S4).

Transitioning to O-COPUS

As we transitioned to online synchronous instruction during ERT, observers continued to code observations using the original COPUS codebook (Smith et al., 2013b). Observers took detailed notes of instructor behaviors and their uses of online functions, such as the messaging function, as well as student behaviors. When observers attended online classroom observations, instructors would make them co-host of the online meeting, allowing them to see reactions better, such as raised hands and thumbs up, as well as permission to move throughout breakout rooms. Observers coded classroom observations synchronously so private features in the messaging function, such as direct messaging, could not be captured. During observations, observers took detailed notes of how instructors and students utilized online functions, such as those mentioned above, which would be the basis for identifying new codes.

Qualitative Coding Process to Adapt COPUS Codes for O-COPUS

We began developing O-COPUS code descriptions using an exploratory coding process with data-driven (inductive) choices (Saldaña, 2015). To do this, during online synchronous observations, we identified the new online teaching and learning behaviors in the COPUS notes section (Smith et al., 2013b). Then, we used a deductive approach to assign the observed online teaching and learning behaviors to a pre-existing COPUS code that related to the students and instructor's behaviors. During the last cycle of analysis, we refined the codes descriptions using focused coding and then we reached coder agreement through group consensus. In this last cycle, our research team determined the inclusion (and exclusion) of O-COPUS codes and code descriptions (File S5, S6).

O-COPUS Validity

Originally, COPUS was developed and validated to measure student and instructor behaviors inside the in-person classroom (Smith et al. 2013). To ensure trustworthiness of the COPUS results, authors of the original COPUS protocol obtained feedback from science education specialists and K-12 instructors to ensure the code and code descriptions were valid in capturing student and instructor behaviors (Smith et al. 2013). This is an example of validation through peer review or debriefing (Creswell & Miller, 2000). To ensure trustworthiness of O-COPUS results, multiple validity approaches were implemented including using prolonged engagement in the field, peer review, and rich, thick descriptions (Creswell & Miller, 2000). First, as described in detail in the sections above, our team has been collecting COPUS data since 2018 indicating our prolonged engagement in the field and understanding of the tool. Second, like Smith et al. (2013), we used peer review or debriefing by getting feedback from a group of STEM educators and discipline-based education researchers (DBER) at a research-intensive university unrelated to the institution in this study (n = 11). The expert feedback panel activities were organized into two parts. In the first part, authors TP and APV collectively presented a subset of the instructor and student codes for the panelists to evaluate the O-COPUS code descriptions. To do this, we showed panelists the original COPUS code descriptions compared to our O-COPUS code descriptions and asked panelists if: 1) these behaviors were applicable to them in online synchronous instruction; 2) there were any additional behaviors that they had observed which we should be included; and 3) any of our code descriptions needed further clarification. Authors AS and PK were present to take notes on the feedback. Originally, our O-COPUS codebook contained the original COPUS descriptions (Smith et al., 2013b), our research team's clarifications of the COPUS code descriptions, as well as our O-COPUS code descriptions.

However, the expert panel suggested that we focus our code descriptions on online behaviors, not clarifications to in-person COPUS codes. For instance, in our original codebook, we clarified that our research team included the instructor going over learning outcomes as a *lecturing* behavior instead of *administration*. Our expert panel pointed out that this was not a change that emerged because of online synchronous instruction, rather our team's interpretation of the code. Hence, we created our COPUS FAQ (Files S1, S2) files to demonstrate our interpretations of the in-person COPUS codes and not distract from our O-COPUS code descriptions. Additionally, based on the feedback received from the expert panel, we realized that some of our original O-COPUS code descriptions were not specific enough. For example, our original O-COPUS code description for *moving and guiding* was: "Moving throughout breakout rooms guiding students or guiding students while they are working on a problem or clicker question (hints/working through a problem) using the microphone or chat function during active learning tasks." However, our expert panel determined that "guiding students while they are working on a problem or clicker question" was not specific enough to translate to a *moving and guiding* behavior. Therefore, we adjusted our O-COPUS code description for *moving and guiding* to include specific instructor behaviors: "Moving through breakout rooms guiding ongoing student work during active learning task or guiding students while they are working on an active learning task by providing hints or working through a problem using the microphone or messaging function." Lastly, the expert panel pointed out that the original vocabulary we were using in our code descriptions, such as "chat", "microphone", and "annotation tool," were specific to the platform Zoom; however, not all institutions utilized Zoom as their online meeting platform for synchronous online instruction. Therefore, we adjusted the terminology used in the code descriptions to fit multiple meeting applications, such as Skype or Google Meet, so other institutions could adapt our codebook even if they used a different application (Tables 2-3). Our original O-COPUS codebook with the feedback from the expert panel can be found in supplemental materials (File S7) as well as our development flowchart of O-COPUS (File S8). Third, we used rich, thick descriptions of the codes and code descriptions to convey our O-COPUS findings in the results that follow.

Our expert panel suggested that we focus our code descriptions on online behaviors, not clarifications to in-person COPUS codes.

O-COPUS Reliability

Once we developed and validated our O-COPUS codebook, we trained 23 SATAL interns following the same training as mentioned above, but we utilized both in-person and online synchronous lecture recordings. To quantify the degree of agreement between observers, we calculated IRR using Fleiss' Kappa. Before conducting online observations, we trained observers until we reached substantial agreement (κ = 0.67, 95% CI: 0.66-0.67) (File S9). In addition to training for both in-person and online observations, observers met for up to 30 minutes after each observation to discuss codes and resolve any inconsistencies until reaching 100% agreement.

Results

Instructor O-COPUS Code Descriptions

We adjusted COPUS code descriptions to fit online synchronous instruction, incorporating new online functions such as breakout rooms and polling without adding or removing codes.

We adjusted six of the 12 instructor COPUS code descriptions to document the teaching behaviors we observed during online synchronous instruction as illustrated in Table 3. We did not change any of the original COPUS codes, but rather adjusted their code descriptions to fit the new usage of online tools seen in online synchronous instruction such as the messaging function. Most adjustments to the COPUS code descriptions were the result of new online functions, such as breakout rooms, polling, and the messaging function, rather than pedagogical changes. Therefore, we did not add any new codes or remove any of the original COPUS codes from our final codebook. Tables 3 and 4 present O-COPUS codes and code descriptions for instructor and student behaviors, respectively. To make our O-COPUS code descriptions more inclusive for other meeting software programs, we used the terms "messaging function" and "chat function" interchangeably. See Supplementary Materials for full descriptions of the codebook which includes inclusion and exclusion criteria for instructor and student behaviors (File S6, S7).

Breakout Rooms

Moving and Guiding (MG)

We changed the code description for *moving and guiding* by adding newly observed behaviors as well as excluded behaviors that no longer fit online synchronous instruction. During online synchronous instruction, instructors could no longer physically move around the classroom, so we utilized this code when the instructor moved in and out of breakout rooms and guided students in their active learning activity. We also found instructors engaged in *moving and guiding* behaviors without having to move throughout breakout rooms. For example, we also coded *moving and guiding* when an instructor assigned an active learning activity and provided students hints to answer a problem or showed students how to solve the problem as they were working on it. We agreed that this was also a moving and guiding behavior even though the instructor did not create breakout rooms because they were still guiding students in an active learning activity (Table 3).

One-on-One (1o1)

We changed the code description for *one-on-one* to better describe online synchronous instruction. Specifically, it occurred when the instructor was moving between breakout rooms and staying with one group for an extended period of time. This behavior would be similar to the instructor walking around the classroom and spending extended time with student groups during group work.

Administration (Adm)

We adjusted the description of *administration* to include scenarios that we frequently encountered during online synchronous instruction, like assigning breakout rooms or assigning an *individual thinking* question that was not a *clicker question* (e. g. think-pair-share). While these behaviors could be interpreted in the "etc." of the original description, we included them to ensure consensus of coding these behaviors during observations.

Polling

Clicker Question (CQ)

Next, for the *clicker question* code description, we added online functions that appeared during online synchronous instruction. The most prominent online activity we observed were online polls such as those used on Zoom or third-party sites (e. g. Poll Everywhere, Socrative, or Mentimeter) which we coded as a *clicker question*. While not identical, online polls allowed students to think individually and submit their answer to a multiple-choice question as well as see the distribution of student responses like a *clicker question*.

Table 3
O-COPUS Instructor Coding Scheme

	Individual COPUS Code	In-person COPUS Code Description	Online COPUS Code Description
Instructor is Doing	Moving and guiding (MG)	Moving through class guiding ongoing student work during active learning task	Moving through **breakout rooms** guiding ongoing student work during active learning task **or guiding students while they are working on an active learning task by providing hints or working through a problem using the microphone or messaging**
	One-on-one (1o1)	One on one extended discussion with one or a few individuals, giving undivided attention to one or a group of students	One on one extended discussion with one or a few individuals, giving undivided attention to one or a group of students **in a breakout room**
	Posing a question (PQ)	Posing non-clicker question to students (non-rhetorical) and waiting for students to respond	Posing non-clicker question to students (non-rhetorical) **using the microphone or messaging function and** waiting for students to respond
	Answering questions (AnQ)	Listening to and answering student questions with the entire class listening	Listening to and answering student questions **using the microphone or messaging function** with the entire class listening
	Clicker question (CQ)	Asking a clicker question (mark the entire time the instructor is using a clicker question, not just when first asked)	Asking a clicker question **or online poll** (mark the entire time the instructor is using a clicker question, not just when first asked)
	Administration (Adm)	Administration (assign homework, return tests, etc.)	Assigning homework, returning tests, **class announcements/agenda, assign to breakout rooms, etc.), when the instructor is waiting for students to answer a non-clicker question (i.e., think-pair-share), or administering a test or quiz**

Note: Descriptions of the in-person COPUS code descriptions adapted from Smith et al. (2013a). Modifications to online COPUS code descriptions are noted in bold.

Chat

Posing a Question (PQ) and Instructor Answering Questions (AnQ)

Lastly, for the codes *posing a question* and *answering questions*, we found that the chat function allowed instructors to ask and answer questions in two ways - verbally or written through the chat. Therefore, we slightly changed these code descriptions to include both modalities.

Student O-COPUS Code Descriptions

We adjusted six of the 13 student COPUS code descriptions to document the teaching behaviors we observed during online synchronous instruction as illustrated in Table 4. While most student codes were easily adaptable to online synchronous instruction, some codes required more adjustments. Most of these code descriptions were adapted to include the online functions used during online synchronous instruction, such as the chat, as well as any new behaviors that emerged because of the implementation of these functions.

Breakout Rooms

Group Clicker Question, Group Worksheet, and Other Group Work (CG, WG, and OG)

During online synchronous instruction, we found group work could be seen in two ways: 1) when the instructor assigned students to work on an active learning activity in breakout rooms; or 2) when students engaged in group work by discussing an active learning activity in the chat without instructor facilitation. For example, in one observation, a group of five students used the chat to work on a clicker question together without any instructor intervention. Since this discussion was not facilitated by the instructor, we concluded it was not a *whole class discussion* but a *group clicker question* instead.

Chat

Student Answering Questions (AnQ)

Online synchronous instruction requires adaptations to traditional COPUS coding, including accounting for chat functions and group work in breakout rooms.

The code description for *answering questions* includes all the ways that students could answer a question during online synchronous instruction. The first and most direct way a student could answer a question posed by the instructor was by responding verbally using the microphone function while the rest of the class was listening. The second way a student could answer a question posed by the instructor was by using the chat function available for everyone in the class to read. We determined this to be interchangeable with "the rest of the class listening" as the original code description for *answering questions* stated. However, in some observations, we noticed that some students' responses in the chat were unnoticed by the instructor. Furthermore, while it was possible for students to answer an instructor's question through private messaging, observers were unable to see these responses during online synchronous observations. Therefore, the description to the code *answering questions* was adjusted to explicitly state "student answering a question posed by the instructor using the microphone or chat function *and* the instructor acknowledges the answer with the rest of the class listening." Additionally, we noticed that throughout the class session some students would ask and respond to each other's questions in the chat, sometimes without the instructor's intervention. This is a behavior that went unseen during live COPUS observations. To acknowledge that these students received an answer to their questions, we deemed it appropriate to code *answering questions* and added "or student answering another students' question using the chat function" to the O-COPUS code description (Table 4).

Whole Class Discussion (WC)

Online synchronous instruction allowed students to be involved in a *whole class discussion* utilizing different functions, including the chat, writing, or drawing function. If multiple students answered an instructor's question using the chat, writing, or drawing function, then we coded *whole class discussion*. For example, if the instructor asked the class to use the drawing function to draw a cell structure on a slide and multiple students participated, then observers coded it as *whole class discussion*. Another example of a *whole class discussion* would be if the instructor posed a question to the class and multiple students responded in the chat.

Student Question (SQ)

The description for the code *student question* was slightly altered to account for the modalities that a student could ask a question during online synchronous instruction -

Table 4
COPUS Coding Scheme

	Individual COPUS Code	In-person COPUS Code Description	Online COPUS Code Description
Student is Doing	Answering questions (AnQ)	Student answering a question posed by the instructor with rest of class listening	Student answering a question posed by the instructor **using the microphone function, reaction function, annotating function, or messaging function and the instructor acknowledges the answer with the rest of the class listening or student answering other students' questions using the messaging function**
	Whole class discussion (WC)	Engaged in whole class discussion by offering explanations, opinion, judgment, etc. to whole class, often facilitated by instructor	Instructor poses a question or facilitate a whole class discussion in which 2 or more students answer **verbally, using messaging function, or drawing function while the rest of the class is listening**
	Group Clicker Question (CG)	Discuss clicker question in groups of 2 or more students	Discussing clicker question in groups of 2 or more students **in breakout rooms or messaging function**
	Group Worksheet (WG)	Working in groups on worksheet activity	Working in groups of 2 or more students on worksheet activity **in breakout rooms or messaging function**
	Other Group Work (OG)	Other assigned group activity, such as responding to instructor question	Working in groups of 2 or more students on other assigned group activity, such as responding to instructor question **or collaborating on a shared document/ website, in breakout rooms in breakout rooms or messaging function**
	Student Question (SQ)	Student asks question	Student asks question **using the microphone or messaging function**

Note: Descriptions of the in-person COPUS code descriptions adapted from Smith et al. (2013a). Modifications to online COPUS code descriptions are noted in bold.

verbally or through the chat function. Similar to *answering questions*, students could ask the instructor questions privately through the chat function; however, observers are unable to see these behaviors during online synchronous instruction unless the instructor explicitly acknowledges they received a private message with a question. Additionally, the original code description for *student question* did not specify that the whole class must be listening, unlike the original code description for *answering questions*. Therefore, regardless of whether the instructor acknowledged a students' question, we used *student question* to code this behavior.

Analyzing Sample O-COPUS Data

O-COPUS can be a valuable tool for instructors teaching in-person, synchronously online, or both, to gain insights into their teaching practices and adapt accordingly.

To understand how online synchronous instruction impacted instructor and student behaviors, we compared one instructor's in-person and online instructor and student behaviors (Figure 1) using the finalized O-COPUS coding scheme (Tables 2-3). This instructor was observed three times in fall 2019 (in-person) and in three times in spring 2021 (online synchronous instruction during ERT). To compare this instructor's COPUS and O-COPUS codes, we took the number of two-minute time intervals marked for each code and divided it by the total of two-minute time intervals for the class session (Kranzfelder et al., 2020; Lewin et al., 2016; Lund et al., 2015). We visualized the changes between in-person and online synchronous teaching and learning behaviors by using pie charts. This is an example of how instructors who teach in-person, synchronously online, or both can utilize O-COPUS to understand better how their teaching practices may differ between the two learning environments (Figure 1).

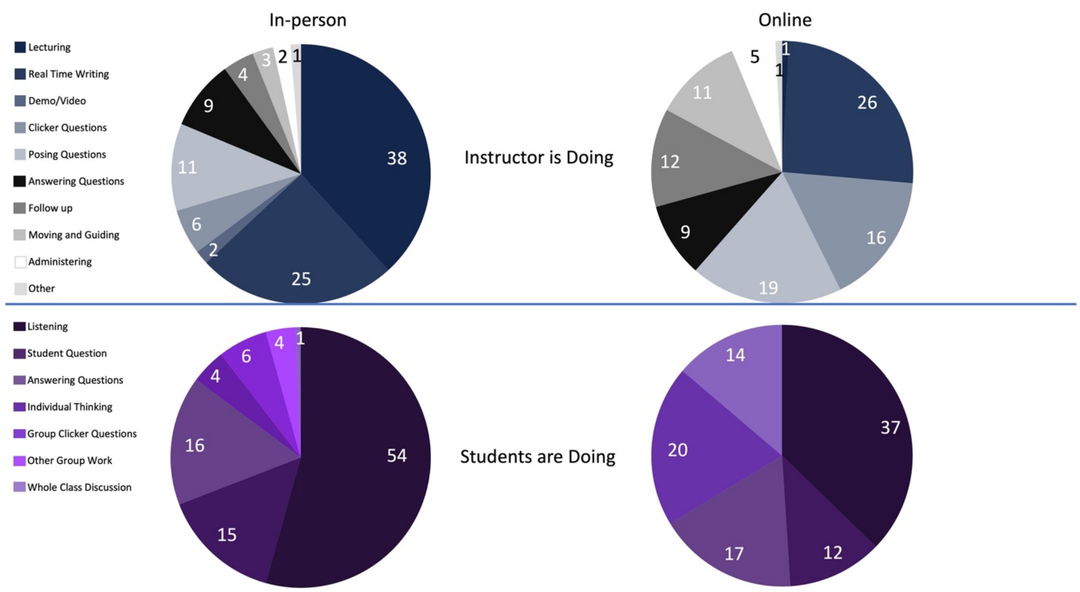

Figure 1
A comparison of the average percentage of two-minute time intervals spent on individual instructor and student COPUS/O-COPUS codes from one STEM instructor averaged across three different class sessions during in-person and online synchronous instruction.

Discussion

We developed and validated O-COPUS to measure teaching practices in the synchronous online format. More specifically, we adapted six instructor COPUS code descriptions to better represent the observed online teaching practices: *moving and guiding*, *one-on-one*, *administering*, *clicker questions*, *posing questions*, and *instructor answering questions*. Moreover, we adapted six student COPUS code descriptions that better represent the observed online synchronous learning behaviors: student answering questions, *whole class discussion*, *group clicker question*, *group worksheet*, *other group work*, and *student question*. The changes in our O-COPUS code descriptions demonstrated that the overall teaching and learning practices in the classrooms we observed did not change; however, the utilization of online functions caused these practices to look different during online synchronous instruction. From the development of O-COPUS, we saw that in-person active learning practices could be translated to online synchronous instruction using online functions, such as breakout rooms, chat, and polling.

Applications of O-COPUS

The innovative teaching practices and online functions instructors adopted to engage their students during online synchronous instruction can be used as instructors teach in different learning environments. O-COPUS results can benefit instructors, institutional assessment programs, and biology education researchers in many ways. Overall, O-COPUS can be applied to: 1) understand the teaching and learning behaviors instructors adapted during online synchronous instruction during ERT; 2) how these behaviors changed between in-person and online synchronous instruction; and 3) make decisions on what teaching practices to implement when instructors return to in-person/hybrid instruction, or if instructors return to online synchronous instruction in the future.

First, O-COPUS allows instructors to continue utilizing formative assessments to explore the teaching practices that could be implemented in online synchronous instruction. O-COPUS data informs instructors if their perceptions of their teaching and learning practices are aligned with observed teaching and learning practices. Additionally, O-COPUS data provide insight to instructors about how they are utilizing their class time to help them realize if their teaching and learning practices might be promoting or inhibiting student cognitive engagement (Chi & Wylie, 2014; Fredricks et al., 2004). For instance, an instructor using a clicker question via a polling function during online synchronous instruction (an example of a constructive mode of engagement) is more likely to promote student cognitive engagement than lecturing and writing notes on an electronic whiteboard (an example of a passive mode of engagement) (Chi & Wylie, 2014). If observers were not capturing the chat function, COPUS data would not reflect the whole class discussions and questions being asked and answered by the instructors and students in the chat. Furthermore, if observers did not capture breakout rooms, online group work would go unnoticed in the COPUS data. Therefore, this adaptation of COPUS for online synchronous instruction was essential to capture the active learning strategies that could not be captured with the original COPUS code descriptions and provide instructors with formative assessment data for their own teaching professional development purposes.

Second, if instructors have previously received in-person COPUS data, then they can compare their two sets of data to see if and how their teaching practices have changed, or not, between in-person and online synchronous instruction. As we examined in our sample data, visualizations such as these can be helpful to show the instructor what teaching and learning practices were used during online synchronous instruction to inform future iterations of courses. More specifically, instructors can use their O-COPUS data to explore what online functions promoted the most student cognitive engagement during in-person and online active learning strategies (Chi & Wylie, 2014). For example, if instructors notice an increase of student cognitive engagement in online synchronous instruction due to the use of the chat function, they may consider how they can continue to use these online functions during in-person, hybrid, or hybrid-flexible instruction (Keiper et al., 2021; Kohnke & Moorhouse, 2021; Miller et al., 2021).

O-COPUS can be used by institutional assessment programs to assess and improve the quality of online synchronous instruction and to ensure that instructors are meeting the learning objectives and goals of their courses.

Third, as some universities begin to return to in-person, hybrid, or hyflex instruction, O-COPUS and COPUS can be used to record both the online and in-person teaching and learning practices. By having a standard protocol for both the in-person and online synchronous instruction, it will allow for consistent classroom observations between the two class formats. If instructors decide to incorporate online functions into the in-person learning environment, COPUS and O-COPUS can be implemented together to document instructor and student behaviors. We hope this tool will support instructors in understanding and improving their own teaching practices as well as provide researchers with a tool that can be used consistently during online synchronous instruction. Furthermore, if universities continue or revert to online instruction in the future, then instructors can refer to their O-COPUS data to determine what practices were effective for them in the past as well as where they can improve.

Limitations and Future Directions

We acknowledge there are several factors that limit our study, providing opportunities for future studies. First, we conducted a convenience sample at one MSI, UC Merced; therefore, our results have limited generalizability. Our selected participants were teaching introductory chemistry and biology courses based on the focus of the larger grant-funded studies, so we did not employ a systematic approach to ensure even distribution of faculty and students across STEM disciplines at our institution or other institutions. In the future, it would be interesting to collect O-COPUS data across several universities, especially other MSIs, to determine if the teaching and learning practices at our institution are similar to others.

O-COPUS offers a consistent protocol for documenting teaching practices in both online and in-person synchronous instruction, allowing instructors to improve their teaching and researchers to study online instruction.

In addition, we developed O-COPUS while observing instructors using Zoom during synchronous online instruction; therefore, we did not examine if there were differences in teaching and learning practices across different meeting software programs, such as Skype or Google Meet. We recommend future studies utilize O-COPUS to document online behaviors with other software programs to see if new teaching or learning behaviors emerge and if our current code descriptions are applicable outside of the Zoom meeting software program. Furthermore, we hope that future studies will utilize O-COPUS to document how instructors incorporate newfound online functions, such as the chat, during in-person instruction.

As we continue to assess online synchronous instruction, O-COPUS could be complemented by pairing it with other tools to study other variables that influence online instruction. Teacher discourse moves, or the conversational strategies used by instructors to encourage student engagement in science content (Kranzfelder et al., 2020; Warfa et al., 2014), has not yet been studied during online synchronous instruction. Observing instructor discourse alongside instructor behaviors can reveal the quality of active learning strategies used by instructors in online synchronous instruction. For example, instructors may be using student-centered, guiding teaching practices, but taking a teacher-centered, authoritative discourse approach with their students (Kranzfelder et al., 2020). By pairing O-COPUS with discourse protocols, such as the Classroom Discourse Observation Protocol (CDOP) (Kranzfelder, Bankers-Fulbright, et al., 2019), instructors can assess if their teaching practices align with how they are talking to their students.

Finally, we focused on the teaching and learning practices at an MSI, but we did not study how the different student demographics were impacted by changes in the teaching practices because of the transition to online synchronous instruction. In the future, it would be relevant to examine aspects of equity and inclusion as well as power dynamics during online synchronous instruction by taking a closer look at student behaviors. Based on recent studies, Barber et al. (2021) found that first-generation and underrepresented minority students were more likely to have limited access to the internet and computers compared to their white counterparts, suggesting that flexibility on policies and assignments would create more equitable online synchronous instruction. Also, Lee and Mccabe (2021) found that male students dominated in-person discussions in science courses compared to their female counterparts. Furthermore, they found that male students frequently spoke without raising their hands and used assertive language when speaking (Lee & Mccabe, 2021). Online synchronous instruction is unique in that it allows students to participate using both the messaging function and verbally, which may lead to female students participating as frequently as their male counterparts. In the future, we recommend documenting who is talking and students' modes of communication during online, hybrid, and/or in-person instruction.

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