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Titrating Teaching: An Interdisciplinary Case Study of Online and Face-to-Face Undergraduate Biochemistry Instruction‡

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Although many science education researchers have investigated developing science education at the K–12 levels to meet the needs of underrepresented students in science, far fewer have considered how shifts to online instruction in undergraduate science courses might provide insights into better supporting the achievement of students from diverse backgrounds at the university level. This case study aims to fill this gap by engaging in a reflective interdisciplinary "deep dive" into the instruction of one biochemistry professor at a designated Hispanic Serving Institution (HSI), across two distinct modalities: face-to-face and online. The findings reported here suggest that the use of formative assessments and student feedback surveys, as well as responsive instructional strategies, facilitate access to and comprehension of complex material in the online modality, without diminishing achievement. Additionally, the reflective collaboration deployed methodologically in this study highlights how higher education faculty can marshal intellectual resources across distinct disciplines to identify and develop responsive pedagogy in advanced science courses at the university level.

INTRODUCTION

For many, the shift to online instruction in the global pandemic of 2020 further exacerbated ruptures in educational access for students historically underrepresented in higher education (1). Such ruptures threaten to damage a decade of national efforts to diversify science majors at the university level (2). As faculty members who teach at a Hispanic Serving Institution, we are acutely aware of the disparities in STEM education (3, 4), as well as calls for reform in undergraduate STEM education (5), and the commensurate need to teach in ways that bolster diverse students' academic advance (6). Yet we were unsure initially how to best meet our students' needs in an educational environment made even more inequitable by the reach of COVID-19. Given all the challenges, we determined that to effect any substantive change in undergraduate science instruction during the pandemic, we needed to systematically study what we were doing first. Thus, we initiated a collaborative interdisciplinary comparative investigation into a biochemistry undergraduate science course across two distinct modalities (face-to-face, in summer 2019, before the pandemic; and online, in summer 2020, during the pandemic). Our aim was twofold: (i) to identify what worked in transitioning a face-to-face undergraduate science course to an online format; and (ii) to provide a template for reflecting critically on one's own course. We are, respectively, an associate professor of biochemistry with 8 years of teaching experience at the university level (Dr. K) and a professor of education with 18 years of teaching experience at the university level (and 8 at the K–12 level) (Dr. P).

Engaging in an interdisciplinary reflective investigation of one science educator's efforts across two distinct instructional modalities holds promise for multiple reasons. First, given that few STEM faculty begin teaching at the university level with any formal pedagogical training (7–9), working with an education researcher could provide insights into key instructional components, and an interdisciplinary collaboration from the perspectives of biochemistry and education faculty, respectively, would likely yield more than the efforts of a lone researcher (10). Second, this case study addresses recent calls for educators to reflect upon and examine their teaching practices (specifically, content delivery, student interaction, and assessments) to better support student engagement in science (11). Third, increasing recognition of the role individual faculty play in student success in science fields (6, 12) has not been matched by a commensurate focus on individual instructors in higher education in a systematic way (13–15). Finally, as faculty committed to increasing equity and academic opportunity, we were interested in

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deploying our expertise collaboratively to identify effective instructional practices for teaching science online. Because the COVID-19–induced shift to online instruction happened so swiftly, we wanted to identify what was working; we were not looking for an "instructional panacea." Instead, our aim was to understand how science faculty could mitigate differences between face-to-face and online instruction without diminishing achievement or overtaxing instructors (16, 17).

The value in instructional reflection

Building off Schön's "reflections-on-action," in which reflecting upon one's instruction provides opportunities to modify and develop subsequent instructional practices, we posit that the use of focused and meaningful reflective practice (18) will aid in developing our understanding of what works in shifting challenging science courses online (15). Indeed, in a comprehensive analytic review of the literature on facilitating development in undergraduate STEM instruction, reflective practice was identified as the *only* strategy regularly acknowledged as effective (14). Thus, in this case study, we reflect upon Dr. K's undergraduate science instruction across two modalities with the aim of "improving practice, rethinking philosophies, and becoming [more] effective teachers for today's ever-changing student population" (19).

METHODS

In initiating an interdisciplinary case study, we took a page from Hativa, who found that engaging the services of an outside consultant to observe and work with individual faculty in a physics department resulted in improved student ratings of faculty (20–22). We did not know, however, what types of instructional benefits might accrue from looking together at an individual faculty member's undergraduate science instruction. Pointedly, it appears from the literature that this type of systematic study of science instruction in higher education has been limited. Indeed, recent studies highlight the "critical need to investigate STEM faculty's instructional decision and value system and to incorporate these findings into instructional reform efforts" (8, 13).

To these ends, this case study provides a broad description of the key components of two Biological Chemistry (CHEM421) course modalities: Dr. K's summer 2019 face-to-face course (pre–COVID-19) and her summer 2020 online course (during COVID-19), the 2020 course consisting of synchronous and asynchronous meetings. The asynchronous component aligns with "flipped classroom" models, such that (i) new material ("preclass material") was presented prior to synchronous/in-class meetings; (ii) the explanation, elaboration, and engagement of preclass material occurred through active learning in synchronous meetings; and (iii) synchronous ("in-class") attendance was required (23). There were 19 students enrolled in CHEM421 in summer 2019 and 11 in summer 2020. Most students take the class as a prerequisite for health profession degrees and exams, including the MCAT. The smaller class size of summer 2020 may have been due to COVID-19 factors, but over the previous four summers, course enrollment ranged from 13 to 21 students.

We scheduled weekly phone conversations (30 minutes to 1 hour) over spring and summer 2020 to reflect upon and discuss the following CHEM421 course data: grades, assessments, instructional strategies, student evaluations of the course, and preparation time. Our collaborative investigation was exploratory and designed to establish trust so that we could communicate candidly about key aspects of Dr. K's instruction across the two modalities. Beyond being open and direct in conversations about teaching biochemistry, Dr. K was willing to "go under the microscope" to reflect upon and analyze her instruction so that we might help others with their online instructional delivery of undergraduate science courses (14).

Course similarities across the two modalities

CHEM421 courses taught in summer 2019 and summer 2020 were each 5 weeks long and based on the same general course outline, learning objectives, required textbook, and for the most part, weekly topics (Table 1). Enrolled students must pass organic chemistry part 2 (which focuses on organic reaction mechanisms) as a prerequisite. The content of assessments across both modalities was generally the same because the majority were based on the same course topics (see below for a description of the inclusion of additional topics in summer 2020) and related to applying, analyzing, and evaluating in Bloom's taxonomy. Additionally, in both modalities, the bulk of the point allocation on assessments was for short answer and essay questions, and students were required to provide an explanation for their selections in multiple-choice questions. The use of particular question types in a given assessment varied across the modalities for two reasons: (i) Dr. K used assessment responses formatively to design subsequent assessments (i.e., question structures differed depending upon class progress on assessments); and (ii) to diminish the likelihood of cheating from one course offering to the next. In yet another effort to safeguard against cheating, Dr. K does not post answer keys for assessments in either modality. Instead, when graded assessments are returned, Dr. K discusses answers with the class; students may then subsequently request a "regrade discussion" if they feel a written answer deserves more points. Dr. K also required students in the online class to sign and return an "Academic Honesty Statement," agreeing to uphold academic integrity (students were reminded about this commitment before each assessment).

In both summers, quizzes and exams were administered under Dr. K's supervision (except one part of midterm 2, described below). In the face-to-face mode, assessments were administered in the physical classroom, and students

TABLE 1.
Distribution of weekly course topics taught by modality.

Weeks 1–5	Topics Taught in CHEM421 Summer 2019 Face-to-Face	Topics Taught in CHEM421 Summer 2020 Online
Week 1	Welcome and Introduction to CHEM421 Syllabus – Course goals Water – Physical properties Chemical Properties of water Buffers, titration curves Amino Acids Peptides, titration curves Structure, stereochemistry and derivatives Reactions of amino acids Protein purification and analysis Independence Day – Campus closed	Welcome and Introduction to CHEM421 Syllabus – Course goals Water – Physical properties Chemical properties of water Buffers, titration curves Amino acids **Peptides, titration curves** **Structure, stereochemistry and derivatives** **Reactions of amino acids** **Protein purification and analysis** Quiz 1 Discuss practice problem 1 (Synch) Protein structure and str. determination **Protein structure determination continued** **Protein stability and folding**
Week 2	Determination of protein structure Protein stability and folding Quiz 1 Protein stability and folding Protein function Allostery and cooperative binding Mb. and Hb. Review for midterm 1	Discuss practice problem 2 (Synch) Allostery and cooperative binding **Enzymes** **General properties** **Enzyme catalysis** Quiz 2 Discuss practice problem 3 (Synch) Review for midterm 1 Enzyme kinetics **Enzyme kinetics and inhibition**
Week 3	Enzymes General properties Enzymes catalysis Midterm 1 Enzyme kinetics Inhibition and control Carbohydrates Introduction to metabolism Bioenergetics Quiz 2	Midterm 1 Discuss practice problem 4 (Synch) Carbohydrates **Carbohydrates continued** **Introduction to metabolism and bioenergetics** Discuss practice problem 5 (Synch) Review for midterm 2 Glycolysis **Anaerobic fate of pyruvate** **Regulation of glycolysis** **Gluconeogenesis**
Week 4	Glycolysis Anaerobic fate of pyruvate Regulation of glycolysis Review for midterm 2 Regulation of glycolysis Gluconeogenesis Midterm 2 PDH complex and regulation Citric acid cycle	Midterm 2 Discuss practice problem 6 (Synch) ***Glycogen metabolism and regulation*** Discuss practice problem 7 (Synch) PDH complex **Regulation of citric acid cycle** **Electron transport and oxidative phosphorylation**
Week 5	Citric acid cycle continued and regulation Quiz 3 Electron transport and oxidative phosphorylation Review for final exam Final exam	Quiz 3 Discuss practice problem 8 (Synch) Oxidative phosphorylation continued *Fatty Acid Metabolism* Review for final exam Final exam

Bold text represents topics that were covered asynchronously, 2 days each week in summer 2020 (Wednesdays and Fridays). Italicized text represents topics covered in summer 2020 that were not covered in the previous 4 summers of face-to-face instruction, due to time constraints.

were instructed to raise their hand if they had questions. In summer 2020, quizzes and exams were administered during synchronous class meetings using the gallery view on Zoom (students kept their cameras on for the duration of the assessment), and students were instructed to use the chat option (restricted to host only) to ask questions.

Course differences across the two modalities

The primary differences between the two summer sessions were the course modalities (face-to-face versus online), number of weekly course meetings, point distribution, and solicitation of student feedback. The face-to-face course consisted of three weekly in-class meetings (Tuesdays, Wednesdays, and Thursdays), whereas the online course consisted of two "in-class" synchronous meetings (Tuesdays and Thursdays) and two sets of asynchronous lectures (Wednesdays and Fridays) each week, for a total of four "meetings." In the face-to-face course, students met for a total of 9 hours 30 minutes over 3 days each week. In the online course, students met with the instructor via Zoom for 4 hours 20 minutes synchronously over 2 days and engaged with the course for 4 hours 20 minutes asynchronously, for a total of 8 hours 40 minutes each week. Weekly asynchronous meetings generally consisted of two 40-minute lecture videos (in total, 22 asynchronous narrated PowerPoint lectures were created for the online course).

The point distribution between the two offerings was generally identical (Table 2), but in response to the pandemic-related challenges many students were facing in summer 2020, 50 points for asynchronous lecture practice problems were added to the online course total to bolster engagement and scaffold the development of topics. Twenty "participation" points were also added to the online course to encourage students to have their cameras on in synchronous meetings. In the future, because of concerns for students' privacy, participation points will depend upon participating orally or via chat (not being on camera).

One other notable difference between the two courses was that in summer 2020, Dr. K requested informal feedback from the students at the end of week 1, prior to formalizing the lecture schedule for weeks 2 to 5, and again in a confidential survey administered during week 3 (Appendix 1), to check student comprehension in the online course format and make real-time adjustments. These additional requests for feedback were important because Dr. K wanted to be sure the course was not exacerbating the challenges of attending university during the pandemic. Moreover, in reflecting upon the novelty of online instruction, Dr. K had considered putting "easier" topics in the asynchronous lectures (24) and focusing on more challenging topics in the synchronous meetings. But based on student responses, the topics were instead located in asynchronous or synchronous meetings on a scaffolded continuum, predicated on developmentally building comprehension and keeping the students on track to learn.

TABLE 2.
Point breakdown by modality.

Point Breakdown	CHEM421 Summer 2019 Face-to-Face	CHEM421 Summer 2020 Online
Midterm 1	75	75
Midterm 2	75	75
Final exam	100	100
Quizzes	30	30
Practice problems	10	60
Participation	0	20
Course total	290	360

Synching asynchronous teaching: building a virtual structure from brick-and-mortar instructional materials

Below, to determine what worked in transitioning a face-to-face undergraduate science course online and to provide a template for reflecting critically on one's own course, we present the following data from the two modalities: course and assessment grades, university student ratings, instructional strategies, instructor-solicited student feedback, and preparation time.

RESULTS

Overall course grades: a baseline of stability

In both modalities, letter grades were based on a straight scale listed on the syllabus (A– to A+ = 86 to 100; B– to B+ = 76 to 85; C– to C+ = 66 to 75; D = 56 to 65; F <55). Overall course grade distributions in Table 3 reveal a similar percentage of students earned A and B grades in both face-to-face and online course offerings, a higher percentage of students earned a C in the online course, and face-to-face students earned more Ds and Fs. Thus, using the most rudimentary and fundamental means of assessing student learning—course grades—it appears online instruction had an edge over face-to-face instruction. But final course grades are too blunt a tool for illuminating what is working instructionally; to nuance our understanding of what worked in shifting instruction online, we examined the components detailed below.

Assessment grades: modifying midterms, diversifying development

Grade distributions based on modality for quizzes, midterms, and final exams are shown in Table 4. In both modalities, no make-ups were allowed for assessments,

TABLE 3.
Course grade distribution[a] by modality.

Course Grade	A	B	C	D	F	Number of Students
CHEM421 Summer 2019 Face-to-face	6 (32%)	7 (37%)	2 (10%)	3 (16%)	1 (5%)	19
CHEM421 Summer 2020 Online	4 (36%)	4 (36%)	3 (27%)	0	0	11

[a] Reflecting grades after lowest score "drops."

but students could miss one quiz or drop their lowest score (Table 3 takes into account lowest-score "drops"). Looking at Table 4, similar percentages of students across both modalities earned a grade of C or higher in Quizzes 1 and 2. Yet, in Quiz 3, a higher percentage of online students earned an A, and there were no D or F grades. Again, it appears as if the online course held a slight advantage over the face-to-face. This advantage shifted on Midterm 1, however, where a higher percentage of students in the online course received a failing grade (below C), even as a similar percentage of students across both modalities achieved A and B grades.

Reflecting upon the increase in failure rates on Midterm 1 in 2020, as well as the failure rates on Midterm 2 in 2019, Dr. K resolved to modify the structure of Midterm 2 for the online course. Conducted as an in-person exam in summer 2019, in summer 2020, Midterm 2 consisted of two parts: an "in-person" module, administered on Zoom synchronously with the instructor (accounting for 67% of the grade), and a "take-home" module that students completed on their own and turned in 48 hours later (accounting for 33% of the grade) to diminish online synchronous (i.e., "live" on camera) test-taking anxiety. As shown in Table 4, modifying the assessment seemed to make a difference; whereas almost a third of the students (31%) in the face-to-face course received D and F grades on Midterm 2, all of the students in the online modality received a grade of C or higher.

Looking across the grades for the cumulative final, Table 4 indicates that a similar percentage of students received an

TABLE 4.
Grade distributions of assessments by modality (raw assessment data).

	Grade	A	B	C	D	F
CHEM421 Summer 2019 Face-to-Face	Quiz 1	14 (74%)	2 (10.50%)	2 (10.50%)	0	1 (5%)
	Quiz 2	3 (16%)	4 (21%)	4 (21%)	2 (10.50%)	6 (32%)
	Quiz 3a	3 (16%)	7 (37%)	2 (10.50%)	3 (16%)	2 (10.50%)
	Midterm 1	4 (21%)	5 (26%)	6 (32%)	1 (5%)	3 (16%)
	Midterm 2	3 (16%)	3 (16%)	7 (37%)	1 (5%)	5 (26%)
	Final Exam	3 (16%)	5 (26%)	5 (26%)	4 (21%)	2 (10%)
CHEM421 Summer 2020 Online	Quiz 1	6 (54%)	2 (18%)	3 (27%)	0	0
	Quiz 2	4 (36%)	1 (9%)	1 (9%)	2 (18%)	3 (27%)
	Quiz 3	6 (54%)	2 (18%)	3 (27%)	0	0
	Midterm 1	2 (18%)	3 (27%)	2 (18%)	4 (36%)	0
	Midterm 2b	3 (27%)	3 (27%)	5 (45%)	0	0
	Final Exam	2 (18%)	2 (18%)	2 (18%)	5 (45%)	0

[a] Two students were absent for Quiz 3 in summer 2019.
[b] Midterm 2 in summer 2020 was administered in two parts: in-person (on Zoom) and take-home.

A grade on the final exam, whether face-to-face or online. In contrast, a higher percentage of students in the face-to-face course received B and C grades, while a higher percentage of students in the online course received D grades (there were no F grades in the online offering). In the case of the final, then, the edge seemed to favor the face-to-face students, seemingly signaling that students in summer 2019 comprehended more. But such analysis neglects to consider the effects of the pandemic or the technological and household online test-taking instability that may have contributed to these results in summer 2020.

Clarity and difficulty: titrating the balance in online instruction

Our university asks students to complete Student Opinion Questionnaires (SOQs) at the close of every course, and these go into each faculty member's file for retention, tenure, and promotion. Absent other mechanisms and acknowledging the problematic use of such evaluations (25) in retention and promotion decisions for women and faculty of color (26) (of which Dr. K is both), we include the university-mandated student evaluation ratings as a proxy for student perceptions of the course. We also deemed them important for identifying potential problems in the shift to online instruction.

Student ratings of instructor clarity, helpfulness, preparation, and overall performance, as well as student engagement, interest, and stimulation, are included in Table 5. Across the two modalities, ratings and comments were overwhelmingly positive. Typical comments from both groups included: "very clear lectures," "cares for students," and "respectful towards students." Additionally, students in the online course mentioned the practice problems were "helpful." Across both modalities, students felt the course administration (i.e., grading policy, as well as the number, length, and fairness of exams and assignments) was straightforward and fair, even as they found the course "difficult" or "hard." In reflecting upon the challenges of shifting to online instruction in the middle of a pandemic, Dr. K was pleased to note students in both modalities perceived her instructional strategies similarly.

Breaking in breakout rooms: small group interaction and unexpected benefits

Both modalities included the provision of weekly "practice problems" with questions about real-life scenarios to ensure students understood the main points of the lectures. In summer 2019, Dr. K provided these at least once per week, and students formed small groups in the classroom to work on the problems, before coming back as a whole group to discuss them together. In summer 2020, each asynchronous lecture day included practice problems covering concepts presented in the asynchronous lecture videos that were designed to support students' capacity to follow the subsequent synchronous lectures. Practice problems needed to be submitted before synchronous meetings.

To further support student comprehension in summer 2020, students were randomly assigned to breakout rooms (two groups of four and one group of three students) at the beginning of each synchronous meeting for 30 to 40 minutes to go over the practice problems they submitted that morning. As in summer 2019, the instructor rotated at least two times between the small groups (now in breakout rooms) to observe student interaction and answer questions. During these rotations, the instructor found the students engaged, actively collaborating, sharing answers, and holding up images (of graphs or molecules) to the camera, as needed. Students seemed to readily seek Dr. K's help when they had questions. At the end of the allotted time, the breakout rooms were closed, students returned to the general Zoom meeting, and Dr. K called on the different groups to share their answers with the whole class (similar to the structure of small group work in the summer 2019 session).

Unique to the online space, however, when Dr. K entered breakout rooms in week 4, it was common during her second round of rotations to find students engaged in informal conversations about why they were taking the class, or career aspirations, etc. Although this was not something Dr. K had planned for, upon reflection, we realized that assigning groups randomly into breakout rooms resulted in an unexpected benefit of the students getting to know each other a bit during what was an otherwise isolating pandemic period. These realizations were corroborated in student survey responses, in which eight out of the nine respondents found the breakout rooms helpful. Students expressed appreciation for them and said they made the course more "interactive" and "engaging." One student commented "I was even able to make a friend in this class, which is rare in the online environment." These types of responses suggest the organization of the breakout rooms was effective in facilitating engagement and, in turn, supporting student learning in the online course.

Topic coverage: asynchronous lectures and unanticipated opportunities

The integration of two asynchronous recorded lectures every week in the online version of CHEM421 resulted in unanticipated opportunities for including additional topics beyond what Dr. K had time for in summer 2019 (or three previous CHEM421 summer offerings). For example, because topics regularly covered in week 4 in her face-to-face offerings were covered in week 3 in the online course, additional time in subsequent weeks allowed Dr. K to cover "Glycogen Metabolism and Regulation" and "Fatty Acid Metabolism." Thus, the online structure facilitated a broader coverage of topics, a welcome finding that Dr. K plans to build on in future courses.

We posit that several factors may have contributed to

TABLE 5.
Distribution of student opinion ratings by modality.

Student Opinion Ratings Out of 4.0 (with 1 being low and 4 being high)	CHEM421 Summer 2019 Face-to-Face (# of Responses = 7 out of 19 Students)	CHEM421 Summer 2020 Online (# of Responses = 6 out of 11 Students)
Clarity of and adherence to the objectives and requirements of the course	3.71	3.83
Clarity, logic, and coherence of the presentations and explanations of the course material	3.71	3.5
Generation of student interest and appreciation for the course material	3.71	3.67
The stimulation of the students to think independently as provided by class discussions, exams, and assignments	3.57	3.67
Preparation for lectures	3.71	3.83
Overall helpfulness and interest in student's progress	3.71	3.67
Overall performance of instructor	3.67	3.83
Overall evaluation of this course (content, structure, examinations)	3.71	3.83

this unanticipated opportunity: (i) the absence of formal breaks in asynchronous lectures increased the actual focused instructional time students engaged with the material (formal breaks are mandated by the university in face-to-face course offerings; a course of 3 hours 10 minutes requires two breaks); (ii) the increased frequency of instruction from 3 days (face-to-face) to 4 days (online), as well as the associated asynchronous practice problems (required to be submitted prior to the synchronous class meetings), appeared to diminish the need for concept reviewing in synchronous courses (outside of the practice problem discussions in the breakout rooms), while increasing what we consider advancing instructional time (the time spent introducing and teaching new topics); finally, (iii) beyond the individual contributions of each of these aspects, the combined effect of the asynchronous–synchronous lectures, asynchronous practice problems, and synchronous breakout rooms, designed to scaffold student comprehension, appeared to result in increased opportunities for focused and advancing learning.

Student surveys: seeking student comfort and academic progress

In contrast to the face-to-face offering, in which the course schedule was set prior to the start of the course, the online lecture schedule for weeks 2 through 5 was not determined until the end of week 1, after Dr. K solicited student feedback about the synchronous–asynchronous schedule. This week 1 informal student survey and the university-required SOQs were not, however, the only sources of feedback Dr. K solicited from students in summer 2020. In week 3 of the online course, unlike in the face-to-face offering, Dr. K administered an additional confidential survey (with settings that did not require e-mail addresses or registration) asking students about their experiences in the online course (Appendix 1). Nine of the 11 students in the course responded to the optional survey. The majority said they liked having lecture videos and the course set-up, and eight out of the nine students found the breakout rooms useful (only one student felt they were "not helpful"). When asked for additional comments, students said: "I really enjoy this class," "You're doing great," and "I'm very satisfied with the course overall." These informal survey responses gave Dr. K a sense of how the students were doing and allowed for subsequent changes to further support student learning.

Course preparation time: every minute matters

Given the many anecdotal concerns colleagues were expressing about the heavy workload involved in online instruction, we were interested in comparing preparation time across the two modalities. Tallying up hours for instructor preparation (lecturing and prerecording lectures) in both modalities each week revealed the online course involved slightly less preparation and delivery time. Reflecting upon all of the challenges associated with shifting instruction online, this was an important finding. Specifically, in comparing preparation and delivery times across the two modalities, the face-to-face offering consisted of three 3 hour 10–minute lectures, and 2 office hours, for a total of 11 hours 30 minutes each week. The online course consisted of two 2 hour 10–minute synchronous meetings, 4 hours to prepare four 40-minute narrated PowerPoint videos (the baseline PowerPoints were the same as those used in summer 2019; time was spent cleaning them up and recording the narration), 1 hour to upload materials, and 2 office hours, for a total of 11 hours 20 minutes. A 10-minute difference may not seem like much, but we were surprised the online offering did not take more time than face-to-face, given the additional meeting each week and the general exhaustion faculty were reporting about the shift to online instruction. It seems likely that Dr. K's strategic deployment of building on extant resources (e.g., refining PowerPoints and practice problems from previous semesters) contributed to the online course's efficiency.

DISCUSSION

The above findings provide a general template of key components important in reflecting critically on one's own course. Exploring them in relation to two undergraduate biochemistry courses—face-to-face (summer 2019) and online (summer 2020)—illuminated effective practices in shifting instruction online, while revealing the importance of triangulating multiple layers of pedagogic practice. If we looked only at course grades, for example, Table 3 reveals that all of the students in the online course passed the class with a grade of C or higher, while 21% of students in the face-to-face course received nonpassing D and F grades. Neglecting to consider other components might have made the online course appear more effective. Alternatively, with such a superficial analysis, course grade differences may have been attributed to distinctions between the two student populations (yet, as there are no controls for enrollment variations from term to term, similarities between the two groups' Quiz 1 results in Table 4 signal some degree of commonality in academic capacity at course start). Course grades alone, however, do not reveal enough to draw any meaningful conclusions about what worked in shifting Dr. K's biochemistry course online. To understand the effectiveness of the course, we needed to look at multiple data points, in this case, assessments, instructional strategies, point distributions, and student feedback. The more complex picture rendered by looking at the totality of our data split "achievement" across the two courses, with no course a clear "winner," and no losers, either. It may seem odd, but we could not have hoped for anything more in the middle of a global pandemic. These similarities in results lay the foundation for future work, discussed below.

When we dove deeper into the assessments of both the face-to-face and online modalities (Table 4), we saw that students in the face-to-face offering performed better (a higher percentage of students with C or better grades) on both Midterm 1 and the Final Exam. This is in marked contrast with the higher percentage of students in the online modality who received D grades for these exams which were conducted synchronously "live" on Zoom. When we look at Quiz 3 and Midterm 2, however, students in the summer 2020 online course performed better. Once again, if we stopped here, we would have reached a conclusion that fell short of the more complex picture our deeper investigation revealed.

Indeed, in reflecting upon instructional strategies and point distributions relative to assessments across the two courses, the additional practice problem and participation points (50 and 20 points, respectively) likely benefitted the students in the online class. Yet when considering the multiple components relative to one another, it seems misguided to think the additional points alone resulted in all of the students passing the summer 2020 course. It is more likely that the additional lectures, meetings, assignments, and breakout rooms also contributed to an enhanced understanding of the material, as evidenced by the students' Quiz 3 performance. Quiz 3 was administered in the last week of the course, and the results may have reflected not only student academic growth, but an increase in familiarity with the online course structure and the benefits of the combined synchronous–asynchronous format. It is important to note, however, that students' achievement levels on Quiz 3 were reflected in Dr. K's decision to have them take the final in the same way—on camera, synchronously. Ultimately, this decision may have been too optimistic. As we now know, students in the online course did not do as well on the final as they had on the two previous assessments (Midterm 2 and Quiz 3). It seems reasonable to intuit, therefore, that on a high-stakes exam (like a midterm or final), providing more than one test-taking modality (as Dr. K did on Midterm 2) is important, especially in online courses, where students may be anxious about the exams themselves and some may additionally struggle with a lack of privacy or control over their home environments.

Given the discrepancies on the final exams, we cannot be certain which individual data point (i.e., the use of asynchronous lectures, the take-home midterm component, additional requests for student feedback, etc.) influenced effectiveness the "most." What we do know is that there was not a significant diminishment in achievement across the modalities. Nor was there a diminishment in student opinion ratings. Table 5 highlights the consistency of instructor performance across the two modalities; ratings for various aspects of the course were comparable, both quantitatively and qualitatively. Recognizing that STEM instructors "rarely pursue discussions about student experiences because it might be thought to be irrelevant to the learning material" (16), Dr. K's willingness to share and analyze both student evaluations was particularly noteworthy.

Triangulating key course components—assessment and final grades, instructional strategies, and preparation times—in relation to student course evaluations and surveys adds to our understanding of the impacts of instructional decisions on student learning experiences in challenging science courses, both as a means of modifying instruction for future students and as a window into student thinking on "the present state of the student–teacher relationship,

[and] perception of student confidence level with instructional content" (17).

CONCLUSION

Collectively, our case study reveals several elements that appear beneficial when moving undergraduate science instruction from face-to-face delivery to online, while illustrating that effective undergraduate science instruction online can be cultivated without an inordinate increase in instructor preparation time. Given the multilayered and integrated nature of our findings, incorporating the five strategies listed below appears beneficial in shifting instruction online:

1. Make narrated asynchronous lecture videos available before synchronous lectures *and* record synchronous lectures and make them available after meetings to aid in student comprehension. This allowed for greater topic coverage (in summer 2020) and appears to have facilitated student learning and performance, as indicated by student grades and qualitative surveys and as noted in previous studies (23).
2. Randomly assign students to different breakout rooms for approximately 30 minutes or more of focused, collaborative work each synchronous meeting, over the duration of the course, to foster heterogenous student interaction, engagement with course material, and, possibly, friendship. Visible student engagement in the breakout rooms, as well as student achievement and qualitative feedback, signaled appreciation for using breakout rooms.
3. Scaffold comprehension by attaching meaningful "real-life" practice problems to asynchronous lectures. Practice problems reinforcing the main points of the asynchronous lectures served as "conduits" of learning by scaffolding comprehension in two ways: outside of the synchronous sessions when they were completed, and within synchronous sessions when they were discussed in breakout rooms.
4. Solicit feedback from students via confidential surveys during the session to facilitate real-time modifications to the course. Dr. K was able to reschedule office hours, modify assignment due dates, and finetune the online course structure based on survey responses, all of which may have increased students' sense of belonging (because they could see that their concerns were heard and valued) (12), as well as contributing to student learning and performance in the online class.
5. Diversify assessments such that they do not all hinge on being "present" or visible online. Integrating a take-home component to Midterm 2 was a manageable and compassionate first step in expanding the ways in which students exhibit comprehension (and one that considers the hardships inherent in being "on camera" at home) and appeared to make a difference in course achievement.

Clearly, a single case study of one professor's undergraduate science instruction across two courses is limited in its scope. But examining the discreet dimensions of instructional practice in relation to the ways in which these aspects cohere into the whole of science teaching does illustrate the depth, complexity, and possibilities of science education at the undergraduate level. It also provides a baseline from which we can investigate integrating more targeted culturally relevant instructional strategies in future research (27). This type of reflective case study, moreover, provides insights into how shifts in individual instructional delivery (from face-to-face to online) in the higher-education context "carry inherent knowledgeability (e.g., ritual, conventions, affordances) while simultaneously [being] open to real-time transformation" (18). It is clear from the data presented above that this "real-time transformation" happens incrementally and interdependently, in tiny titrations that collectively result in opportunities for student interaction, engagement, and comprehension, whether face-to-face or online.

SUPPLEMENTAL MATERIALS

Appendix 1: Midpoint confidential student survey questions in summer 2020, online

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