Teaching in a Time of Crisis

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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, 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 (HSI), 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 affect 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 2-fold: (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 and a professor of education with 18 years of teaching experience at the university level (and 8 at the K–12 level).

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 in an examination of 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 (s 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 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 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) which consisted 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 pre-class 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 past 4 summers, course enrollment ranged from 13 to 21 students.

We scheduled weekly phone conversations (between 30 min and 1 h) 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, based upon 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 two (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 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.
| Wk 1 – 5 | Topics taught in CHEM421 Summer 2019 Face-to-Face | Topics taught in CHEM421 Summer 2020 Online |
|----------|--------------------------------------------------|---------------------------------------------|
|          | Welcome and Introduction to CHEM 421             | Welcome and Introduction to CHEM 421        |
|          | Syllabus – Course goals                          | Syllabus – Course goals                     |
|          | Water-Physical Properties                        | Water-Physical Properties                   |
|          | Chemical Properties of Water                     | Chemical Properties of Water                |
|          | Buffers, Titration curves                        | Buffers, Titration curves                   |
|          | Amino Acids                                       | Amino Acids                                  |
|          | Peptides, Titration curves                        | Peptides, Titration curves                   |
|          | Structure, Stereochemistry and Derivatives       | Structure, Stereochemistry and Derivatives  |
|          | Reactions of amino acids                          | Reactions of amino acids                     |
|          | Protein Purification and Analysis                | Protein Purification and Analysis           |
|          | Independence Day - Campus closed                 | Independence Day - Campus closed            |
| Wk 1     | Determination of Protein Structure               | Discuss Practice Problem 2 (Synch)          |
|          | Protein Stability and folding                    | Allostery and Cooperative Binding           |
|          | Quiz 1                                            | Enzymes                                     |
|          | Protein Stability and folding                    | General Properties                           |
|          | Protein Function                                 | Enzymes Catalysis                           |
|          | Allostery and Cooperative Binding                | Quiz 2                                      |
|          | Mb. and Hb.                                      | Discuss Practice Problem 3 (Synch)          |
|          | Review for MT 1                                  | MT1 Review                                   |
|          |                                                    | Enzyme Kinetics                              |
|          |                                                    | Enzyme Kinetics and Inhibition              |
| Wk 2     | Enzymes                                          | Midterm 1                                   |
|          | General Properties                                | Discuss Practice Problem 4 (Synch)          |
|          | Enzymes Catalysis                                | Carbohydrates                               |
|          | Midterm 1                                         | Carbohydrates continued                     |
|          | Enzyme Kinetics inhibition and control            | Introduction to Metabolism and Bioenergetics|
|          | Carbohydrates                                    | Discuss Practice Problem 5 (Synch)          |
|          | Introduction to Metabolism                       | MT2 Review                                   |
|          | Bioenergetics                                    | Glycolysis                                   |
|          | Quiz 2                                            | Anaerobic fate of pyruvate                  |
|          |                                                    | Regulation of glycolysis                     |
|          |                                                    | Gluconeogenesis                              |
| Wk 3     | Glycolysis                                       | Midterm 2                                   |
|          | Anaerobic fate of pyruvate                       | Discuss Practice Problem 6 (Synch)          |
|          | Regulation of Glycolysis                         | Glycogen Metabolism and regulation          |
|          | Review for MT2                                   | Discuss Practice Problem 7 (Synch)          |
|          | Regulation of Glycolysis                         | PDH Complex                                  |
|          | Gluconeogenesis                                   | Regulation of TCA cycle                     |
|          | Midterm 2                                         | Electron Transport and                       |
|          | PDH Complex and regulation                       | Oxidative Phosphorylation                   |
|          |                                                  |                                            |
| Wk 4     | Citric Acid Cycle continued and regulation       | Quiz 3                                      |
|          |                                                    | Discuss Practice Problem 8 (Synch)          |
|          | Electron Transport and                            | Oxidative Phosphorylation continued         |
|          | Oxidative Phosphorylation                        | Fatty Acid Metabolism                        |
|          | Review for Final Exam                            | Review for Final Exam                        |
|          | Final Exam                                        | Final Exam                                   |

Bold text are topics that were covered asynchronously, 2 days each week in Summer 2020 (Wednesdays and Fridays). Italicized text are topics covered in Summer 2020 that were not covered in the previous 4 summers of face-to-face instruction, due to time constraints.
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 (18) and focusing on more challenging topics in the synchronous meetings. But based upon 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.

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+ = 86–100; B— to B+ = 76–85; C— to C+ = 66–75; D = 56–65; 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, 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, as a higher percentage of students in the online course received failing grades (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 did on their own and turned in 48 h later (accounting for 33% of the grade) to diminish online synchronous (i.e., “live” on-camera) test-taking anxiety.

### TABLE 3
Course grade distribution by modality

| Course grade | A   | B   | C   | D   | F   | no. of Students |
|--------------|-----|-----|-----|-----|-----|----------------|
| CHEM421      |     |     |     |     |     |                |
| Summer 2019  |     |     |     |     |     |                |
| Face-to-Face | 6   | 7   | 2   | 3   | 1   | 19             |
|              | (32%) | (37%) | (10%) | (16%) | (5%) |                |
| CHEM421      |     |     |     |     |     |                |
| Summer 2020  | 4   | 4   | 3   | 0   | 0   | 11             |
| Online       | (36%) | (36%) | (27%) |     |     |                |

Reflecting grades after lowest score “drops.”

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

| Grade | A       | B       | C       | D       | F       |
|-------|---------|---------|---------|---------|---------|
| Quiz 1 | 14      | 2       | 2       | 0       | 1       |
|        | (74%)   | (10.50%)| (10.50%)| (5%)    | (10.50%)|
| Quiz 2 | 3       | 4       | 4       | 2       | 6       |
|        | (16%)   | (21%)   | (21%)   | (10.50%)| (32%)   |
| Quiz 3* | 3       | 7       | 2       | 3       | 2       |
|        | (16%)   | (37%)   | (10.50%)| (16%)   | (10.50%)|
| Midterm 1 | 4      | 5       | 6       | 1       | 3       |
|        | (21%)   | (26%)   | (32%)   | (5%)    | (16%)   |
| Midterm 2 | 3      | 3       | 7       | 1       | 5       |
|        | (16%)   | (16%)   | (37%)   | (5%)    | (26%)   |
| Final exam | 3      | 5       | 5       | 4       | 2       |
|        | (16%)   | (26%)   | (26%)   | (21%)   | (10%)   |

CHEM421 Summer 2019 Face-to-Face

| Grade | A   | B   | C   | D   | F   | no. of Students |
|-------|-----|-----|-----|-----|-----|----------------|
| Quiz 1 | 6   | 2   | 3   | 0   | 0   |                |
|        | (54%) | (18%) | (27%) |     |     |                |
| Quiz 2 | 4   | 1   | 1   | 2   | 3   |                |
|        | (36%) | (9%) | (9%) | (18%) | (27%) |                |
| Quiz 3 | 6   | 2   | 3   | 0   | 0   |                |
|        | (54%) | (18%) | (27%) |     |     |                |
| Midterm 1 | 2   | 3   | 2   | 3   | 3   |                |
|        | (18%) | (27%) | (18%) | (27%) | (27%) |                |
| Midterm 2 | 3   | 3   | 5   | 0   | 0   |                |
|        | (27%) | (27%) | (45%) |     |     |                |
| Final Exam | 2   | 2   | 2   | 5   | 0   |                |
|        | (18%) | (18%) | (18%) | (45%) |     |                |

CHEM421 Summer 2020 Online

*Two students were absent for Quiz 3 Summer 2019. **Midterm 2 in Summer 2020 was administered in two parts: in-person (on Zoom) and take-home.
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 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 (24) in retention and promotion decisions for women and faculty of color (25) (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 toward 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 min 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/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 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, in 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 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 h and 10 min 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 were designed to scaffold student comprehension and 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 email 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, and the majority said they liked having lecture videos and the course set-up, and eight out of the nine students found 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 pre-recording 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-h and 10-minute lectures, and 2 office hours, for a total of 11 h and 30 min each week. The online course consisted of: two 2-h and 10-minute synchronous meetings, 4 h 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 h to upload materials, and 2 office hours, for a total of 11 h and 20 min. 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
It seems likely that Dr. K’s strategic deployment of building on extant resources (i.e., refining PowerPoints and practice problems from previous semesters) contributed to the online course’s efficiency.

**DISCUSSION**

The findings above 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. Administered in the last week of the course, results for Quiz 3 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 when students may be anxious about the exams themselves and for some, 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 appear 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, 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 fine-tune 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 difference in course achievement.

SUPPLEMENTAL MATERIALS

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

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