Full title: COVID-19 and the abrupt shift to remote learning: Impact on grades and perceived learning for undergraduate biology students

Short title: Impact of COVID-19 on student learning

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Abstract

Institutions across the world transitioned abruptly to remote learning in 2020 due to the COVID-19 pandemic. This rapid transition to remote learning has generally been predicted to negatively affect students, particularly those marginalized due to their race, socioeconomic class, or gender identity. In this study, we examined the impact of this transition in the Spring 2020 semester on the grades of students enrolled in the in-person biology program at a large university in Southwestern United States as compared to the grades earned by students in the fully online biology program at the same institution. We also surveyed in-person instructors to understand changes in assessment practices as a result of the transition to remote learning during the pandemic. Finally, we surveyed students in the in-person program to learn about their perceptions of the impacts of this transition. We found that both online and in-person students received a similar small increase in grades in Spring 2020 compared to Spring 2018 and 2019. We also found no evidence of disproportionately negative impacts on grades received by students marginalized due to their race, socioeconomic class, or gender in either modality. Focusing on in-person courses, we documented that instructors made changes to their courses when they transitioned to remote learning, which may have offset some of the potential negative impacts on course grades. However, despite receiving higher grades, in-person students reported negative impacts on their learning, interactions with peers and instructors, feeling part of the campus community, and career preparation. Women reported a more negative impact on their learning and career preparation compared to men. This work provides insights into students' perceptions of how they were disadvantaged as a result of the transition to remote instruction and illuminates potential actions that instructors can take to create more inclusive education moving forward.

Introduction

In the early months of 2020, the COVID-19 pandemic led to an unprecedented disruption of the normal mode of course instruction across most institutions of higher education. In the United States, most universities abruptly stopped conducting in-person classes and closed their campuses in March 2020 [1,2]. Mid-semester, many students and instructors were forced into learning and teaching remotely, respectively, for the first time due to the need for social distancing as a response to the pandemic [3,4]. Syllabi, teaching approaches, and assessments had to be modified to account for this altered mode of learning; most instructors only had one to two weeks to redesign their courses before remote instruction began. This abrupt shift to remote learning has been distinguished from online learning in general [5] and it is commonly assumed that this abrupt shift adversely affected student learning [6,7]. There are many factors directly associated with the shift to remote learning that could have affected student learning [5,7], which are in addition to the stress experienced by students in other aspects of their lives affected by the pandemic (e.g., health, employment, isolation, issues of inequality).

The pandemic affected people across various social identities such as age, nationality, racial/ethnic background, LGBTQ+ status, and socio-economic status. Despite being termed as “the great equalizer” by politicians like New York’s Governor Andrew Cuomo and celebrities such as Madonna [8,9], it had differential impacts on people along the lines of power and privilege in our society due to various systems of oppression including, but not limited to, racism, classism, sexism, and ableism [9–13]. In the United States, case and death rates have been higher among Black, Hispanic/Latinx, and Native American people than white people [14–16]. COVID-19 infections and deaths were also higher for people living in areas with higher poverty levels compared to areas with little or no poverty [17,18]. Further, these more vulnerable communities experienced more negative financial impacts such as job losses or reduced

working hours due to the economic shutdowns [19]. Moreover, some studies have reported more negative mental health impacts of the pandemic on women, Hispanic, and Asian people [20], and on people living in lower-income households [21]. When considering the educational impact of this crisis, it is important to ask if these differential medical and financial impacts contributed to more negative educational consequences for students with marginalized social identities.

In addition to health and financial impacts, several other factors may have differentially exacerbated the negative effects of the COVID-19 pandemic on student learning in Spring 2020. Losing access to student housing and meal plans contributed to housing and food insecurities for many students, including low-income students and international students [22,23], and heightened housing and food insecurities impacted off-campus students as well [24]. Moreover, poor internet connection and lack of a quiet or safe space to study made it more difficult for students to complete their assignments and succeed during remote instruction [25–28]. For example, one recent study of college students in introductory sociology courses showed that more than 50% of all students experienced occasional internet problems during remote learning in Spring 2020 [29]. In the same study, about 90% of the students reported distractions in their new workspace and about 65% of the students reported the lack of a dedicated workspace [29]. While these issues negatively affect all students, students from low-income families are disproportionately impacted by poor internet connections or distracting environments. Another factor that likely affected remote learning in Spring 2020 is additional caregiving responsibilities necessitated by remote learning in K-12 schools and greater health risks for older family members [30]. These additional responsibilities would reduce time for coursework and could affect academic outcomes. Likely due to societal gender roles that assume women take on primary caregiving, these responsibilities are reported to have disproportionately affected women [30–32]. The privilege of staying at home or having safe working conditions to reduce

the risk of exposure to COVID-19 has also been shaped by axes of power in our society [33–35]. Needing to work jobs that require frequent interaction with others at places such as grocery stores and pharmacies is yet another element influencing student learning during the pandemic, especially for Black, Hispanic/Latinx, immigrant students, and those from low-income households [36]. Working such jobs could increase students' risk of exposure to the virus and may cause greater anxiety in their daily lives [37,38]. All these factors are likely to differentially affect students depending on their locations along the various axes of power and privilege.

A limited number of studies have examined the educational impact of the pandemic on students. Several publications have reported that students were less engaged [39] and struggled with their motivation to study after the transition to remote learning in Spring 2020 [25,29,40,41]. One study on public health students at Georgia State University did not report lower motivation among students [42], perhaps because of the heightened awareness of the relevance of public health during a global pandemic. It has also been demonstrated that the transition to remote learning had a negative impact on student relationship-building, specifically the extent to which students interact with each other in and out of class [25,43], and on students' sense of belonging in the class [25]. In response to the pandemic, several universities changed course policies to extend the deadline for course withdrawals or to allow greater access to pass/fail grading options [44]. Villanueva and colleagues [28] found higher course withdrawal rates among general chemistry undergraduates after students were offered an extended deadline for withdrawing from the course. Despite these negative student experiences, some studies have reported small increases in student grades in Spring 2020 compared to similar courses in previous years [45–47].

There is some evidence for differential impacts of the transition to remote learning for students with different social identities. For example, a report based on survey data from 600

122 undergraduates in STEM courses across the US showed that women, Hispanic students, and
123 students from low-income households experienced major challenges to continuing with remote
124 learning more often than men, white students, and students from middle- or high-income
125 households, respectively [25]. Another survey study found that the likelihood of lower-income
126 students delaying graduation because of COVID-19 was 55% higher than higher-income
127 students [48]. Additionally, Gillis and Krull [29] reported that women experienced challenges
128 such as lack of a dedicated workspace more often than men, while non-white students
129 experienced anxiety over personal finances and access to medical care more often than white
130 students.
131
132 In contrast to students in in-person degree programs whose mode of learning changed
133 drastically, the crisis did not fundamentally change the mode of learning for students who were
134 already enrolled in fully online degree programs. Although other aspects of the lives of online
135 students were still affected by the pandemic, online learning was not new to them or their
136 instructors, courses did not need to be modified halfway through the term, and students
137 expected to complete all coursework remotely when they signed up for the course. Therefore,
138 comparing the impact of the pandemic on the grades of online and in-person students might
139 allow us to tease apart the influence of the rapid transition to online learning from the stress of
140 living through a global pandemic. One prediction would be that online students would
141 experience less of a negative impact on learning due to the pandemic compared to their in-
142 person counterparts because their educational modality did not change. An alternative
143 prediction is that the differences in the student populations online and in-person, specifically the
144 higher percentage of individuals in the online program who hold one or more marginalized social
145 identities and may be more vulnerable to the negative effects of the pandemic outside the class,
146 would lead to greater negative impacts for online students as a result of the COVID-19
147 pandemic. Specifically, we know that the percentage of women, older students, students who

are primary caregivers, and students from low-income households are consistently higher in online programs compared to in-person programs [49–51]. These are groups that have been unequally disadvantaged during the pandemic in general. Therefore, it is important to control for demographic variables when comparing the effects of the COVID-19 pandemic on grades between students in online and in-person degree programs.

Current Study

The biology program at Arizona State University (ASU) offers a unique opportunity to examine the impact of the emergency transition to remote learning on undergraduates. First, ASU offers equivalent in-person and fully online biology degree programs that have aligned curricula. This allows for comparison of the experiences of students in an in-person program transitioned to remote learning, to the experiences of students enrolled in an online program prior to the COVID-19 pandemic. In this study, following the recommendation from Hodges et al. [5] we use the term “remote” to refer to in-person courses that transitioned abruptly to online instruction, while using the term “online” for courses that were designed to be online from the beginning. One important difference between the online and in-person programs after the transition to remote learning in Spring 2020 was that courses in the online program were fully asynchronous. In contrast, the courses in the in-person program were generally taught synchronously using web conferencing (e.g., Zoom) for lectures and typical in-class activities.

Second, ASU has a large, diverse population of students that allows for the examination of the extent to which the transition affected students with different social identities. Science, technology, engineering, and math (STEM) disciplines, such as biology, have long been exclusionary spaces dominated by relatively wealthy white men [52–54]. Underrepresentation of women, people of color, people with disabilities, and people with low socioeconomic status is

well documented in the sciences [55]. Therefore, it is important to examine the impact of the transition to remote learning on STEM students with social identities historically underrepresented in the sciences, for which ASU's biology program provides a suitable context.

This study uses course grades during the Spring 2020, Spring 2019, and Spring 2018 semesters and survey data from instructors and students about the Spring 2020 semester to examine the impacts of the abrupt transition to remote learning due to COVID-19 during the Spring 2020 semester.

Specifically, our research questions were:

1. Did the abrupt transition to remote learning due to the COVID-19 pandemic affect grades for undergraduate students in an in-person biology program during the Spring 2020 semester? Was this effect on grades different from that found in the equivalent online biology program during Spring 2020? To what extent did the abrupt transition to remote learning disproportionately affect students with identities historically underrepresented in STEM?

2. What changes did in-person biology instructors make to their assessment practices after the abrupt transition to remote learning in Spring 2020 and to what extent do these explain any differences in student grades observed?

3. To what extent do in-person biology students perceive that their learning, interactions with peers and instructors, career preparation, interest in science, and feeling a part of the biology community were affected because of the abrupt transition to remote learning? To what extent did the abrupt transition to remote learning disproportionately affect these perceptions for students with identities historically underrepresented in STEM?

Positionality of the authors

We acknowledge that our own identities influence the research questions that we ask and how we may interpret the data. Our author team includes individuals who identify as men, women, white, South Asian, Jewish, first-generation college-goers, first-generation immigrants, and members of the LGBTQ+ community; members of our team grew up in middle class families in the United States, except KS who grew up in India. All the authors are committed to diversity, equity and inclusion in the sciences and conduct education research focused on equity. This paper was motivated by our concerns regarding social inequities and how they are perpetuated and, in some cases, amplified in undergraduate science classrooms.

Methods and Results

Research Question 1: Assessing the impact of the abrupt transition to remote learning due to the COVID-19 pandemic on grades for undergraduate students in an in-person biology program compared to an online biology program.

Research Question 1, Methods

To study the impact on student course grades that resulted from the shift to remote learning during the COVID-19-impacted Spring 2020 semester, we obtained course grades from the university registrar for Spring 2020 and compared these grades to two spring semesters prior to the pandemic: Spring 2019 and Spring 2018. The population of interest is undergraduate biology majors enrolled in either the in-person biology degree program or the fully online biology

degree program. Therefore, we obtained course grades for 42 STEM courses that are commonly taken by students in these biology majors, including general biology courses, biochemistry, chemistry, physics, mathematics, and statistics. See Table S1 for the full list of courses.

Our grades analysis included a total of 25,100 student-course enrollments, with 8,323 from the Spring 2020 pandemic semester and the remainder from Spring 2018 or 2019. Of these, 19,181 course enrollments were in-person courses and the remaining 5,919 were online degree program courses. Course grades were analyzed on a 0–4.33 scale (A+ = 4.33, A = 4.0, A- = 3.66,..., E = 0). Grades other than A–E were excluded from analysis; this was a total of 2,404 student-course enrollments, or 9.6% of the total dataset. In Spring 2018 and 2019, these excluded grades are almost exclusively W or “withdraw” grades. In response to the unique circumstances of the pandemic, some instructors assigned the “Y” grade which indicates “Satisfactory” work at a level of C or higher. In Spring 2020, about a third of the non-letter grades were Y grades. The combined proportion of non-letter grades held steady in Spring 2020 compared to 2018 and 2019 in online courses and increased slightly in Spring 2020 for in-person courses. The withdrawal percentage declined, and the Y percentage rose both online and in-person. We cannot say definitively how many of the students who received a Y grade would have chosen to withdraw if this option had not been available. The decision to remove these grades from analysis is consistent with prior studies [51,56]. To control for prior academic performance, we use “GPAO,” which refers to a student’s grade point average in other courses, including both STEM and non-STEM courses [56,57].

We obtained student demographic information from the registrar in addition to course grades (summarized in Table 1). The categories of interest for this study are gender, race/ethnicity, and two proxies for socioeconomic status (college generation status and federal Pell grant eligibility).

246 The transition away from an in-person lecture and having to adapt to a large change mid-
247 semester could also have negatively affected the learning of students with disabilities [7] as
248 changing learning environments have presented novel challenges for deaf and hard of hearing
249 students [58] and students with disabilities more broadly [7]. However, because we are using
250 institutional data in these analyses and data on disabilities is protected by federal law, we were
251 not able to examine the impact of the transition on students with disabilities in this study, nor
252 were we able to explore other identities not routinely collected by the university registrar.
253
254 **Table 1. Demographics for students in the in-person and online course grades data set**.
255 Pell eligibility and college generation status are included as proxies for socioeconomic status.
256 BLNP refers to Black, Latinx, Native American, and Pacific Islanders.
257

	In-Person Students	Online Students
Characteristic	N = 4,671[1]	N = 2,586[1]
Gender		
Man	1,652 (35%)	675 (26%)
Woman	3,019 (65%)	1,910 (74%)
Other	0 (0%)	1 (<0.1%)
BLNP		
N	3,058 (65%)	1,662 (64%)
Y	1,613 (35%)	924 (36%)
Race/Ethnicity		
White	2,242 (48%)	1,431 (55%)
Asian	625 (13%)	128 (4.9%)
Black	245 (5.2%)	224 (8.7%)

	In-Person Students	Online Students
Characteristic	N = 4,671[1]	N = 2,586[1]
Hispanic	1,168 (25%)	547 (21%)
Native	65 (1.4%)	39 (1.5%)
Two or more races	273 (5.8%)	159 (6.1%)
Decline to state	53 (1.1%)	58 (2.2%)
Pell Eligible		
N	2,689 (58%)	1,079 (42%)
Y	1,982 (42%)	1,507 (58%)
College Generation Status		
Continuing Generation	3,169 (68%)	1,458 (56%)
First Generation	1,502 (32%)	1,128 (44%)

[1]n (%)

To determine the direction and significance of the effect of the shift to remote learning on student grades, we performed a linear mixed-effects regression on the numerical course grades. The fixed effects in the model included a dummy variable for the Spring 2020 ("COVID-19") semester, whether the student was enrolled in the in-person or online degree program, an interaction between these two variables, and the GPAO term. We included random effect terms for course section and student. These terms provided modest improvement to the models with a combined intraclass correlation coefficient equal to 0.256.

To determine the direction and significance of the effect of the shift to remote learning on grades received by students with identities historically underrepresented in STEM, we added interaction terms between the dummy variable for the Spring 2020 ("COVID-19") semester and each of the demographic terms to the model described above. We again controlled for GPAO and included

271 random effect terms for course section and student in this model (see Table S2 for model
272 specifications).
273

274 Research Question 1, Results

275 Overall, our linear mixed effects regression results show that the Spring 2020 semester was
276 associated with a positive grade shift of 0.41 grade units. Students earned higher grades in
277 Spring 2020 courses compared to students enrolled in those courses in Spring 2019 and Spring
278 2018. Results also show that this Spring 2020 grade effect was not significantly different
279 between the online and in-person programs (Table 2). The online program is also associated
280 with lower course grades overall, which is consistent with our prior work [51].
281

282 **Table 2. Linear mixed effects regression results showing Spring 2020 ("COVID-19") effect**
283 **and its interaction with instruction mode.**

Variable	Beta	95% CI[1]	p-value
(Intercept)	0.12	0.05, 0.20	0.002
GPAO	0.89	0.87, 0.91	<0.001
Spring 2020	0.41	0.36, 0.46	<0.001
Campus			
In-Person	—	—	
Online	-0.27	-0.38, -0.15	<0.001
Spring 2020 * Campus			
Spring 2020 * Online	-0.11	-0.33, 0.11	0.3

[1]CI = Confidence Interval

284
285 Our regression model testing for the presence of negative interaction effects between
286 demographic groups and the Spring 2020 semester showed no significant negative interactions

for any of the demographic variables that we examined, including gender, race/ethnicity, and socioeconomic status (Table S3). Contrary to our prediction, the model shows positive, but mostly non-significant, interaction effects for all groups compared to their historically overrepresented counterparts. The two statistically significant interactions showed women to have a Spring 2020 effect 0.05 greater than men and Pell-eligible students to have an effect 0.08 greater than non-Pell-eligible students.

Research Question 2: Understanding biology instructor changes to assessment practices in the Spring 2020 semester when they transitioned to remote learning and their effects on differences in student grades.

Research Question 2, Methods

To better understand why the COVID-19 pandemic did not negatively affect course grades in the Spring 2020 semester for students who had to transition to remote learning, we sought to understand what steps in-person biology instructors took to ensure that their students could achieve the course goals after the abrupt transition to remote learning. To explore this, we created a survey with several open-ended questions regarding changes in instructional practices, such as modes of interaction with students and assessments used after the transition to remote learning (a copy of the survey questions analyzed is provided in the Supplemental Materials). Of the 132 biology instructors recruited to participate, 27 instructors responded to the survey (20% response rate). Faculty members were recruited first via email, and verbally

encouraged to participate at several follow-up virtual events attended by many of those in the recruitment group.

Building on the open-ended responses from the first instructor survey, we created a second survey that asked in more detail about instructional changes in response to the pandemic. To assess cognitive validity, we conducted two think-aloud interviews with biology faculty members who taught in person during Spring 2020 and had to transition to remote learning [59]. These think-aloud interviews indicated that the instructors understood the questions. We then distributed this revised survey to all biology instructors who taught in-person courses in Spring 2020 (n=132). In the event that they taught multiple courses, the survey asked them to respond based on their largest course size. The survey first asked instructors to identify any changes they made in their course. This question used a multiple-selection format with a) 24 options provided, b) an option to say that no changes were made, and c) an option to describe other changes not listed. The survey also asked instructors to report the extent to which they tried to reduce cheating in their course, the extent to which they made their course more flexible, and the extent to which they made their course easier. Each of these questions was answered using a six-point Likert scale from strong agreement to strong disagreement with no neutral option and they were asked to explain each answer (a copy of the survey questions analyzed is provided in the Supplemental Materials). While instructors also experienced many of the same personal challenges resulting from the pandemic that students did, our focus was on the student experience and therefore we only asked instructors about instructional changes.

A total of 43 out of the 132 biology instructors who were contacted completed the second survey (33% response rate) based on their experiences teaching an in-person biology course that shifted to fully remote instruction in the Spring 2020 semester. Of these, 18 had taught an in-person course that transitioned during Spring 2020 with at least 100 students. Our analysis will

334 focus on these large courses because these instructors are subject to greater practical
335 constraints when considering how to shift instruction to remote learning and because the larger
336 sizes mean that a greater number of students in total are impacted by these decisions.
337
338 To understand the extent to which changes in assessment practices made by instructors might
339 explain differences in student grades in Spring 2020 compared to previous semesters, we
340 examined data from 10 instructors who responded to our survey who had taught the same
341 course in Spring 2020 and either Spring 2019 or 2018. We performed course-level linear
342 regressions on the relative grade difference using the following variables as predictors: total
343 number of changes made, use of lockdown browsers for exams, whether they made efforts to
344 reduce cheating, and whether they worked to make the course easier. All variables were
345 dichotomous except number of changes made. The question about making the course more
346 flexible was not included because all ten of the instructors who had taught the same course in
347 Spring 2020 and Spring 2019 or 2018 agreed with this question.
348

349 Research Question 2, Results

350 Overall, most instructors reported making changes to their in-person courses when they needed
351 to transition to remote learning during the COVID-19 pandemic, including being more flexible
352 and making the course easier (Table 3). Focusing on the large courses, about 60% of
353 instructors agreed that they took steps to reduce cheating. Nearly all large course instructors
354 (94%) agreed that they made changes to be more flexible to help students who were
355 experiencing challenges and most (78%) agreed that they made it easier for students to do well.
356

357 **Table 3. Summary of in-person instructor survey responses about the changes they**
358 **made to their course after the transition to remote learning in Spring 2020.**

Survey Item	Large Class Instructors N = 18[1]	Small Class Instructors N = 25[1]	All Instructors N = 43[1]
Made more flexible	94%	84%	88%
Made easier	78%	56%	65%
Tried to reduce cheating	61%	32%	44%
Number of changes selected	4.7 (3.2)	3.1 (3.5)	3.8 (3.4)
Zero changes selected	5.6%	24%	16%

[1]%; Mean (SD)

Instructors were also asked to select the changes they made to their largest in-person course that had to transition to remote learning in that semester from a list of 24 options (Table 4, See Supplemental Table 4 for the full set of options). On average, instructors of large courses selected about five changes. The most frequently selected changes were generally related to time and deadline extensions as well as conducting open-book exams. Changing the weighting or number of exams or changing the difficulty of questions on quizzes or exams were less commonly selected. Thirteen respondents added open-ended comments in addition to the provided choices. Five of these related to changes needed to replace planned fieldwork or labs. The remainder detailed specific content-related adjustments or discussed changes to increase instructor availability to students.

Table 4. Frequencies of selection of fixed choice options for course changes by in-person instructors after the transition to remote learning in Spring 2020. This table only shows options chosen by ≥25% of respondents; for full results, see Table S4).

Response Option	Frequency N = 43

Gave individual students extensions on deadlines for out-of-class assignments that I wouldn't have normally provided	37%
Extended the deadline or allotted more time than I usually provide to complete out-of-class assignments	33%
Increased the amount of time students were allotted to complete a quiz or exam	33%
Gave students more opportunities to miss class and not lose participation/attendance points but still gave participation/attendance points for class	26%
Reduced or eliminated penalties for out-of-class assignments that were submitted late	26%
Changed assessments such as exams or quizzes from closed-book to open-book	26%
In addition to delivering my content online I made a significant change to my course that is not reflected above	30%

Within our subset of surveyed instructors who had taught the same class in Spring 2020 and one of the prior Spring terms, our linear regression showed that none of the instructional changes in assessment practices were significant predictors of the difference in grades received by the analyzed students in Spring 2020 compared to previous two Spring semesters. Greater instructor flexibility could be associated with the increase in grades across all courses, but we were not able to test this relationship because all ten of the instructors in this subset reported increasing flexibility in their courses.

Research Question #3: Understanding the impact of the abrupt transition to remote learning due to COVID-19 on biology student perceptions of learning, interactions with

peers and instructors, career preparation, interest in science and feeling a part of the biology community.

Research Question 3, Methods

Although the transition to remote learning for students who were in the in-person biology degree program in Spring 2020 did not have adverse effects on their grades, likely in part because instructors made changes to their courses, we wanted to explore student perceptions of learning during Spring 2020. To do so, we surveyed students during Fall 2020 to ask specifically about their experiences during the Spring 2020 semester when their in-person courses rapidly transitioned to remote learning.

Student survey development

To assess the perceptions of biology majors who experienced the rapid transition from in-person to remote instruction in Spring 2020, we developed a survey that contained both closed-ended and open-ended questions. We asked students to think about the largest biology course they took in the Spring 2020 semester to answer the survey questions that were course-specific, (i.e., impact on grades, impact on learning, and perceived instructional changes). For the rest of the survey questions, students were asked to think about all the in-person biology courses they took in Spring 2020. To assess cognitive validity of survey items, we conducted six think-aloud interviews with undergraduate students and iteratively revised survey items until no further changes were suggested [59]. The final survey contained questions about the perceived impact of the rapid transition to remote learning on student learning, grades, interest in their biology major, interest in learning about scientific topics, feeling a part of the biology community at the university, and career preparation. Each question was answered using a seven-point scale from

409 "strong negative impact" to "strong positive impact." In addition, we asked about the impact of
410 the transition on the amount of time spent interacting with instructors and other students, and
411 the amount of spent time studying. These items were also answered using a seven-point scale
412 ranging from "greatly decreased" to "greatly increased." During our think-aloud interviews with
413 undergraduate students, the necessity of a "neutral" option for these survey items was brought
414 up by multiple students. Therefore, we used a seven-point scale for these items instead of the
415 six-point scale used in our instructor survey. We also asked students about perceived
416 instructional changes to the course in terms of measures to prevent cheating, increase flexibility,
417 and make the course easier. These were on a six-point scale from "strongly agree" to "strongly
418 disagree" with no neutral option for consistency with the instructor survey (see Supplemental
419 Materials for the analyzed survey questions).
420
421 We included some demographic questions at the end of the survey so we could test for any
422 differential effects on student experience by social identities, specifically gender, race/ethnicity,
423 college generation status and eligibility for federal Pell grants. For race/ethnicity, we asked
424 students two questions: whether they identified as Hispanic/Latinx and whether they identified
425 as Black/African American, Native American/Alaska Native, or Native Hawaiian/Pacific Islander.
426 Students that selected "yes" to either of these questions were grouped together as BLNP for our
427 analyses. We grouped students in this manner because all these groups are historically
428 underrepresented in the sciences and our sample sizes for the student survey were not large
429 enough to allow us to disaggregate race/ethnicity data.
430
431 **Student survey distribution**
432 In Fall 2020, we used a convenience sampling approach to recruit eight biology instructors who
433 agreed to distribute our survey to students in their classes. The survey was sent to a total of
434 1,540 students in these eight courses and students were offered a small amount of extra credit

435 for completing the survey. A total of 798 students completed the survey, resulting in a response
436 rate of 51.8%. However, only 601 of these students were enrolled in the in-person biology
437 degree program in Spring 2020. Of these students, 70 reported that they did not take any
438 biology courses in Spring 2020, so they were not included in any course-specific analyses. After
439 removing these students and removing 21 students with missing data, we were left with
440 responses from 510 students who had taken in-person biology courses that had transitioned to
441 remote learning in Spring 2020 that we used for our analyses (Table 5). Students were asked to
442 think about the largest in-person biology course they took in Spring 2020 for the survey. This
443 gave us data about student experiences in 25 Spring 2020 courses, although for 13 of these
444 Spring 2020 courses, we had fewer than 10 respondents.
445
446 **Table 5. Demographics for student survey respondents**. Three of the women among the
447 survey respondents also identified as non-binary. One of the men also identified as non-binary
448 and as transgender. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell
449 eligibility and college generation status are included as proxies for socioeconomic status.
450

	Student survey respondents
Characteristic	N = 510[1]
Gender	
Man	165 (32%)
Woman	345 (68%)
Other	0 (0%)
BLNP	
N	358 (70%)
Y	152 (30%)

	Student survey respondents
Race/Ethnicity	
Asian	98 (19%)
Black	17 (3.3%)
Hispanic	108 (21%)
Native	6 (1.2%)
Two or more races	38 (7.5%)
White	219 (43%)
Decline to state	24 (4.7%)
Pell Eligible	
N	336 (66%)
Y	174 (34%)
College Generation Status	
Continuing Generation	357 (70%)
First Generation	153 (30%)

[1]n (%)

Student survey analyses

We calculated the total percentage of students that reported negative impacts on their learning, amount of time studying and interacting with peers and instructors, career preparation, interest in science and feeling a part of the biology community. To analyze the open-ended data, we used open-ended coding methods to identify themes that emerged from student responses [60]. We used constant comparison methods to develop the coding scheme; student responses were assigned to a category and were compared to ensure that the description of the category was representative of that response and not different enough to require a different category. Inter-

rater reliability was established by having two coders (S.E.B. and R.A.S.) analyze 20% of the data, after which one person coded the rest of the data. For student perceptions of the positive impact of the transition to remote instruction on learning codes: Two raters compared their codes and their inter-rater reliability was at an acceptable level (k = 0.88). For student perceptions of the negative impact of the transition to remote instruction on learning codes: Two raters compared their codes and their inter-rater reliability was at an acceptable level (k = 0.88). We report out any code that at least 10 students mentioned.

For eight of the Spring 2020 courses in our dataset, we had data from both the instructor and more than 10 students for each course. For these courses, we assessed if student responses to perceived instructional changes to the course aligned with the instructional changes as reported by the instructors. We analyzed the strength of this relationship through Pearson product-moment correlations between the percent of students agreeing with each statement and the strength of the instructor's agreement using a Likert scale.

To examine demographic differences in the perceived impact on students, we used ordinal mixed model regressions with the Likert scale option chosen by students as the outcome and gender, race/ethnicity, Pell-eligibility, and first-generation to college status as predictors. We used course section as a random effect with varying intercepts in all the models to account for the nested nature of our data. We used the R regression package *ordinal* [61] for these analyses.

Research Question 3, Results

About 56% of students reported that they think the transition to remote learning negatively impacted their grade, even though our grade analysis did not indicate that this was likely.

485 However, almost 70% of students said that transition to remote learning negatively impacted
486 their learning in the same course (Fig 1). We analyzed the reasons why students felt that the
487 transition to remote instruction either positively or negatively affected their learning (Tables 6
488 and 7). For the 30% of students who thought that it positively impacted their learning, they said
489 it did so because lectures were recorded so they could review them or see more of them
490 (18.3%), they felt as though they could learn at their own pace (15.0%), they felt like remote
491 learning allowed them to engage with the material in a more active learning way (11.7%), or
492 they felt more comfortable learning at home as opposed to in a large classroom (8.3%). There
493 was also a subset of students who felt as though they had more time in general during the
494 pandemic, which allowed them to focus more on studying (16.7%). For the 70% of students who
495 reported that the pandemic negatively impacted their learning, 27.2% of students reported that
496 they felt as though they understood less and remembered less during remote instruction (Table
497 7). Students also reported a loss of concentration or focus (26.6), fewer opportunities to interact
498 with others and ask questions (17.0%), and having less motivation or interest (9.9%). Less
499 common responses included: feeling overwhelmed by greater amounts of work after the
500 transition to remote learning (5.9%), lack of hands-on learning, particularly in lab courses
501 (4.0%), general stress associated with the pandemic that increased distractions outside of
502 coursework (3.7%), procrastination and less accountability (3.1%), and technical issues (2.8%).
503
504 **Fig 1. Percentage of students who reported a negative impact or reported a decrease in**
505 **the time spent on various activities during Spring 2020 along with ordinal regression**
506 **results on demographic differences.** BLNP refers to Black, Latinx, Native American, and
507 Pacific Islanders. Pell eligibility and college generation status were included as proxies for
508 socioeconomic status. The reference groups for the regression analyses were: men, non-BLNP
509 students, continuing-generation students and students that were not eligible for Pell grants.
510

511 **Table 6. Positive impacts of the transition to remote learning on student learning**

512 **experiences.**

513

Category	Description	Percent n=60	Example quotes		
Lectures were recorded	Students indicated that they could go back and review the lectures if they needed and they missed fewer classes because they had the recordings.	18.3%	"Recorded lectures greatly helped me understand the content taught."	"Since all lectures from the point of the transition were moved to Zoom, the fact that things were recorded allowed the possibility for me to go back to the recording and stop at points that I needed in order to take notes on certain slides to further my understanding of the topics in case I missed a couple words or explanations through the fast explanations."	"Lectures were recorded and posted online, allowing for the opportunity to review material."
Had more time in general	Students indicated that the pandemic allowed them to have more time to dedicate to coursework and the online nature of courses gave them more time to study.	16.7%	"I had more time to stay home and actually teach myself the material "	"I do feel like I have more time to really understand the material."	"I had more time to study in quarantine."
Learn at own pace	Students could decide when to engage with the material and had autonomy over the pace.	15.0%	"Allowed me to learn at my own pace."	"I could watch lectures on my own time throughout the week."	"I liked being able to watch the lecture videos all at once."
Engaged with	Students indicated that they engaged in	11.7%	"The instructor posted additional	"I use some of the PowerPoints to	"Because of the online format,

material in more of an active learning way	the material before the lecture, they taught themselves more, and they had the opportunity to engage with other students in active learning online.		lecture videos for students so we were familiar with the material before the actual Zoom lectures."	answer practice questions and improve my understanding more independently."	we're able to do small group discussions of papers in breakout rooms. That helps [me] to understand more complex material."
Felt more comfortable learning at home and not in a classroom	Students indicated that they felt they learned better by being at home or not in a large classroom.	8.3%	"Being able to study in my own space comfortably helped me learn a little bit better."	"Not being in lecture with other people distracting me allowed me to take better notes."	"I felt more comfortable with online learning than having a large in-person classroom; there is something different about the ambient and inclusivity about digital learning."

514

515 **Table 7. Negative impacts of the transition to remote learning on student learning**

516 **experiences.**

517

Category	Description	Percent n=353	Example quotes		
Less understanding/ comprehension/ retention	Students mentioned that online learning or video lectures were generally difficult to comprehend. Students indicated that the online format made them feel like they focused more on memorization and less on understanding or that they felt as though they retained and	27.2%	"It felt like I went from going to class and understanding the material to just memorizing to get assignments done. This is especially true for the lab portion of the class."	"Did not comprehend and retain as much information as I could have in person."	"Because everything was more for completion, I focused on getting the assignments answered rather than understanding material. I cannot remember any material from that course."

	remembered less. They felt like they studied less because of open-note exams and were just trying to pass.				
Loss of focus/ concentration	Students felt as though they could not focus or concentrate as well online, and often cited more distractions.	24.6%	"The online teaching didn't click as well with me and I felt it was difficult to focus online because of the distractions that are not present in a classroom, but are present at home."	"I found it more difficult to focus on the coursework compared to when I had my biology lecture in-person."	"I found it more difficult to focus over Zoom."
Fewer interactions/ opportunities to get help	Students indicated that online was anti-social, less personal, and they interacted less frequently with other students and the instructor. Specifically, they were not able to clarify their thinking, ask questions of students or instructors, and felt like they were on their own.	17.0%	"Not being in person to ask questions felt a little limiting. When going on campus I was also able to ask classmates questions before and after class."	"It was harder to learn the material without being able to engage with the teacher. She did most of her lectures as pre-recorded ones."	"For all my biology courses, it would have been better to have an in-person class where I could ask my friend beside me to explain small things or even the TA's who were walking around."
Students had less motivation/ interest/effort	Students indicated that online they had less motivation, less interest in the topics online, and put in less effort. Students discussed a lack of connection with	9.9%	"It was more difficult to engage and interact with the material so I was less interested in actually learning it."	"The feeling of determination and want to learn slipped for some reason for myself personally and I just slid by in the course instead of actually trying to learn the material."	"It's incredibly hard to absorb information from a digital perspective, think about it, we (students) watch tons of videos online in our free time, watching an online lecture is like watching a super boring

	or engagement in the material.				YouTube video. I think professors need to think of ways to make things more engaging!"
Overwhelmed by work/ increased work	Students felt as though online learning increased the total amount of work in the course, increased the pace of the course, and/or the course felt rushed.	5.9%	"I felt the class was sped through [because] it moved online and it was all rushed and I didn't feel like I was retaining anything."	"I felt like we were being forced to do more work for not having to attend in person."	"I felt as though I couldn't learn anything because there was so much that needed done, so I was trying to meet deadlines."
Lack of hands-on learning	Students reported that online there were not opportunities for hands-on learning, specifically doing experiments in labs.	4.0%	"It was more difficult to learn the material by attending the online calls for lectures and labs. The hands-on connection was not there."	"With everything online, the topics were more impersonal. Usually being able to look at the cadavers and doing hands-on activities facilitated learning for me."	"Concepts became harder to understand, particularly for lab. This is because there was no hands-on learning."
Pandemic stress	Students felt stressed in general by the pandemic. Students worried about their health, employment, housing, schooling of their children, and other issues outside of academics that interfered with their learning.	3.7%	"It was difficult to pay attention to lectures knowing that my safety was uncertain and I may not have a place to live."	"It is difficult to remember the Krebs cycle when the world is burning down around you."	"So many students like myself were going through a 'grieving' period when the second quarter of this semester started, some of us had lost family members, had moved back in to abusive households, and to add the heavy load of school was anything but easy."

Procrastination/ less accountable/ less incentive to do well	Students felt as though they procrastinated on work and were less accountable for attending class and doing their work in the course.	3.1%	"In class, I was held accountable to pay attention and to focus. The lectures were really long and when I was at home I was spacing out and talking to my roommates etc. I also let myself get behind in lecture because I knew they were going to be available to watch at a later time."	"I did not feel as motivated right away to keep up with topics on my own. Skipping lectures became easier than in-person ones."	"Again, since the lectures in [an introductory biology course] had no clicker questions, I didn't attend them as regularly as I should have."
Technical issues	Students cited technical issues online that took up time, including internet issues or not being able to access materials.	2.8%	"As classes transitioned, lots of technical difficulties amongst other things caused extreme stress and anxiety."	"Sometimes the computer could skip a word or two that the professor said. This would make it a little harder to keep track of what was being lectured."	"Sometimes not all the material was covered in class due to technology difficulties or the professor was not able to use this online platform."

Our analyses of the closed-ended Likert scale data showed that a large proportion of students (67.1%) reported that the transition to remote learning in Spring 2020 had a negative impact on their career preparation. A relatively smaller but still significant proportion of students reported a negative impact of the transition to remote learning on their interest in their biology major (31.5%) or interest in learning about scientific topics (37.1%). However, many more students (66.9%) reported a negative impact of the transition to remote learning on their feeling of being a part of the biology community at the university. See the Supplemental Materials for full Likert scale response for each of the survey items.

Most students reported that the amount of time they spent on interactions with instructors and other students, both in and outside of class, decreased as a result of the transition to remote

learning. In fact, about 63% of students said that the amount of time they spent interacting with other students in class and outside of class greatly decreased in Spring 2020, which was the strongest response option (Table S11). However, student responses were fairly split on the amount of time spent studying for a course, with about 45% of students reporting an increase in the amount of time they spent studying and 41% reporting a decrease (Fig 1).

We collected student and instructor data on instructional practices for eight courses. Among these, only four of the eight instructors agreed that they took steps to reduce cheating in their course and the percentage of students in a given course taught by one of these four instructors who agreed that their instructor took some steps to reduce cheating ranged from 90 to 100%. However, even for the courses where instructors disagreed that they took steps to reduce cheating, 83 to 86% of students agreed that their instructor took some steps to reduce cheating (Figure S1). By contrast, all eight of these instructors agreed that they tried to make their course more flexible. However, there was more variation in student response to whether their instructor tried to make the course more flexible with the percentage of students who agreed with this statement ranging from 61 to 91% across the eight courses. All but one instructor agreed that they tried to make the course easier, but the student agreement with this question was again mixed ranging from 47 to 81% across the courses. Overall, these data show that students tended to slightly overestimate instructor efforts to reduce cheating and slightly underestimate instructor efforts to make the course easier and more flexible.

We did not find significant demographic differences in the student Likert responses to most of the survey items. In Fig 1, we describe the few demographic differences we found through our ordinal mixed models (see full ordinal regression results in the Supplemental Materials). Although most students reported that the time spent with instructors decreased or greatly decreased during the pandemic, the proportion of BLNP students that chose these options was

lower than non-BLNP students. Pell-eligible students were more likely to report that time spent with other students in class greatly decreased compared to students that were not Pell-eligible. Lastly, women were significantly more likely than men to report negative impacts on their learning in a course and on career preparation.

Discussion

Contrary to our predictions, transition to remote learning due to the COVID-19 pandemic in Spring 2020 did not have a negative effect on student grades and instead had a small positive effect across demographic groups among students enrolled in the in-person and online biology degree programs. Our instructor surveys showed that instructors who had to transition to remote learning increased flexibility and made several other changes in assessment practices that might have contributed to the slight increase in student grades in the in-person courses. Despite this increase in grades, our student surveys revealed several negative impacts of the transition to remote learning, particularly on students' perceived understanding of course content, interactions with other students and instructors, feeling like a part of the biology community at the university, and career preparation. These negative impacts do not seem to have a stronger effect on students with certain social identities over others for the most part. However, women were more likely to report negative impacts on their learning and career preparation compared to men, a result consistent with concerns about widening gender inequities due to the COVID-19 pandemic. Additionally, Pell-eligible students reported a decrease in the amount of time spent in and outside of class interacting with other students more often, which is consistent with concerns regarding logistical difficulties for students from less wealthy backgrounds. Together these findings suggest that instructor responses were effective in mitigating negative impacts on student grades across all demographic groups examined in this study, and notably did not seem to induce any new inequities based on demographics, but that the abrupt transition to remote

learning still led to a diminished perception of learning and career development during the Spring 2020 semester for many students.

The observed mismatch between grades and student perceptions of their learning might be because students underestimated their learning [62]. Some studies have shown that student perceptions of learning can be positively correlated with their grades [63–65]. However, a recent study comparing the effects of active and passive (i.e., lectures) instruction on student learning found that students who received active instruction scored higher on the learning assessment but perceived that they learned less than their peers who received passive instruction [66]. Thus, even though it has been shown that students, on average, learn more from active learning [67,68], students' perception of learning might not match their actual learning. A meta-analysis showed that student perceptions of their learning are more strongly related to affective outcomes, such as motivation and satisfaction, and have a much weaker relationship to learning outcomes, such as scores [69]. However, one reason for this may be that grades are often not an accurate measure of student learning [70]. Given this background and our results that instructors were more flexible with grading after the transition to remote learning in Spring 2020, we think it is likely that the increase in grades does not actually reflect an increase in student understanding of the course material. In contrast, students earned higher grades while self-reporting that they learned less, which we find concerning for the extent to which their completion of these college courses is preparing them for their future careers.

The slight increase in average student grades in Spring 2020 compared to previous semesters is consistent with other studies that have examined student grades in Spring 2020 at other institutions [45–47]. Interestingly, this increase in student grades was observed both in courses that experienced the emergency transition to remote learning and courses in the online degree program that did not experience a transition in modality. Although we did not survey the online

606 instructors, this suggests that both in-person and online instructors may have been responsive
607 to the public health and economic crisis due to the COVID-19 pandemic and became more
608 lenient and flexible in their grading. The increase in student grades was seen across all
609 demographic groups. More specifically, women, Black, Latinx, Native American, Multiracial and
610 Asian students, and Pell-eligible students experienced a similar or slightly larger positive shift in
611 grades as men, white students, and students who were not eligible for Pell grants. Thus, the
612 grade increase in Spring 2020 did not fall along the lines of power and privilege in our society
613 and benefited students with all social identities. A similar result was found in a study on student
614 scores at Victoria University in Australia where the researchers found statistically significant but
615 very small differences in the impact of COVID-19 on student scores between demographic
616 groups [45].
617
618 The instructor surveys show that among our study population, most instructors made
619 accommodations related to deadlines and stated that they took steps to make their courses
620 easier for students to do well. Other studies have also reported greater flexibility among
621 instructors in Spring 2020, including instructors in general chemistry courses at a liberal arts
622 college in the US [28]. A survey study of faculty members and administrators across the US
623 found that 64% of faculty members changed the kinds of exams or assignments they asked
624 students to complete in the course and about half of them lowered expectations on the amount
625 of work from their students in the Spring 2020 semester [3]. Additionally, many universities
626 expanded access to pass/fail grading structure instead of the more traditional A-F letter grades
627 for students, with some institutions even making the pass/fail grading structure mandatory for all
628 courses [44]. Arizona State University allowed faculty members to use the range of grading
629 options that have always been available but perhaps not used as often prior to Spring 2020.
630 That included the traditional A through E grading scale, plus the use of the I or Incomplete grade
631 (allowing students to complete coursework within 1 year of the end of the term) and the Y grade

which indicates “Satisfactory” work at a level of C or higher, similar to the Pass grade at other universities. Thus, our study affirms other reports that the focus across colleges and universities to make courses more flexible and less stressful for students in Spring 2020 may have off-set potential drops in student grades. While we see the benefit of this flexibility for students, particularly that we did not see demographic differences in these grade increases, we do find it concerning that students still felt as though they learned less. We encourage instructors to be thoughtful of what they are doing to make their courses flexible while maintaining the quality of teaching and providing students with ways to engage in deep learning so that they are not disadvantaged at a later timepoint because they have not learned as much as they needed to in that earlier course.

Many students recognized the positive impact of greater instructor flexibility and changes in assessment practices on their grades, while recognizing the negative impact of the transition on their understanding of the course material. This is consistent with other survey studies that show that students perceived a negative impact on their learning or were less satisfied with their learning after the transition to remote learning [25,41,45]. In our study, most students also reported negative impacts on interactions with other students and instructors, career preparation, and a feeling of being a part of the biology community at the university. These are also consistent with other studies on student experiences [25,43]. A larger survey study of in-person students at Arizona State University across various degree programs, the same institution where our study was conducted, found several striking negative impacts on career preparation due to COVID-19. According to this study, 13% of students delayed graduation, 40% suffered the loss of a job/internship, and 29% of students expected to earn less by age 35 [48].

We found similar perceptions of negative impacts on student learning, interactions and career preparation across demographic groups with few significant differences. We found that women were more likely to report negative impacts on their learning and career preparation compared to men. This is not surprising given the greater childcare obligations with school closures and that women spend more time doing unpaid care work compared to men [32]. In an interview study of engineering students, women reported having to spend more time on domestic duties while men described having more free time after the transition to remote learning during the Spring 2020 semester [71]. Together this suggests that the COVID-19 pandemic has exacerbated gender inequities and could have long-term negative impacts on women's education and careers that are not captured in simply examining student course grades. We encourage future studies to explore how the COVID-19 pandemic affected the persistence of women in STEM careers.

The only survey item in which we found a significant difference between BLNP and non-BLNP students was the time spent with instructors, where BLNP students chose the option "greatly decreased" less often. Previous studies show that BLNP students often have more interactions with faculty members compared to white students, although they also have negative interactions with faculty members more often [72,73]. Still, their greater experience of interacting with faculty members might have prepared them better to communicate with instructors during emergency remote learning. High-quality interactions with faculty members have been shown to have positive effects on student learning [72,74,75]. However, BLNP students did not report less negative impacts on learning compared to non-BLNP students. This suggests that even though BLNP students reported a decrease in the time spent with instructors less often, it might not have translated into benefits for their learning.

We also found that students from less wealthy backgrounds (operationalized through federal Pell grant eligibility) more often reported a reduction in time spent with other students in class after the transition to remote learning. Pell-eligible students were also 1.2 times more likely to be working a job after the transition to remote learning and 1.5 times more likely to be working more than 20 hours a week compared to students that were not eligible for federal Pell grants (Table S12). With greater availability of recorded lectures, Pell-eligible students may have attended fewer synchronous sessions, thus further reducing their interactions with other students. Although the decrease in interactions with other students is not desirable, making lectures available for students to watch later might offer students greater flexibility in juggling coursework with other work/family responsibilities. Indeed, some students reported positive impacts on learning after the transition to remote learning due to the availability of recorded lectures and being able to learn at their own pace (Table 6). Overall, instructors may need to find a balance between asynchronous learning to make learning more accessible with synchronous learning to foster peer interactions.

The transition to remote learning had a negative impact on students' interest in their biology major or interest in learning about scientific topics in about a third of the students. A similar study of students enrolled in a general chemistry course at a large public university in the southern United States found no significant change to students' identities and intention to pursue a career in science due to COVID-19 [76]. However, we did not find any demographic differences in student responses to questions about science interest, which is encouraging given the importance of increasing representation of women, Black students, Latinx students, and students that grew up in low-income households in STEM. Almost two-thirds of students reported a negative impact of the transition to remote learning on students' feelings of being a part of the biology community at the university, which is alarming, although not surprising, given that students reported spending less time interacting with both instructors and their peers.

Creating opportunities for increasing interactions using various modes of synchronous and asynchronous communication (e.g., online office hours, discussion boards, apps) might help students feel a greater sense of community and social presence of others in the class.

Instructor responses to our survey items about whether they took steps to prevent cheating, increased flexibility, or made the course easier are in broad agreement with student responses to those survey items. Most students seem to recognize their instructors' efforts during the transition to adapt their courses to the online modality as well as the public health and economic crisis. However, students' underestimation of instructor flexibility and changes to make courses easier suggests that communication between students and instructors might need to be strengthened. Instructors may have needed to use more "instructor talk," which is defined as any discussion that is not specific to the course content, to signify the changes that they were making to the courses and why they were making these changes [77]. It is also possible that the steps that instructors took might not have been sufficient to reach students' needs or expectations. Because instructors tend to be in better financial situations than their students, perhaps they underestimated some of the student challenges. Setting up robust systems of communication among students, instructors, student support staff members, and administrators might improve the academic climate for all stakeholders and prepare us better for future emergencies or needs to change instruction rapidly. Indeed, an interview study with engineering students found that faculty members communicating care and increasing flexibility was a key element for supporting students [71]. In another study, students indicated the need for constant communication from instructors during remote learning [78]. Thus, developing stronger communication with students and improving "instructor social presence" in online courses, i.e., the sense that the instructor is connected and available for interactions is critical [79–81]. This may be done through casual conversations in discussion boards, leveraging social media and using time in class and during office hours to build classroom community.

Limitations

Prior work shows that grades are not an accurate measure of student learning, thus we are limited in our ability to accurately measure the effects of the abrupt transition to remote learning due to COVID-19 on student learning [70,82,83]. Moreover, student perceptions of negative impacts of the transition on their learning that we observed might be attributed to the abrupt transition itself or the difficulty of learning during a pandemic. Surveying students in the online program about their experiences in the Spring 2020 semester could have helped us tease apart these two factors more.

Another limitation of our study is the relatively small sample size for our survey dataset which caused us to group data from Black/African American, Hispanic/Latinx, Native American/Alaska Native and Pacific Islander/Native Hawaiian students for analyses. The histories and experiences of racial oppression of these groups in the United States are different from each other and grouping them together erases these differences. Similarly, grouping white and Asian students together into a group is problematic as well, because there are several different ethnicities included in the category of “Asian” in the US which includes ethnicities that are underrepresented in STEM in the US [84]. Despite limited statistical power, we ran ordinal regressions on the survey data with disaggregated race/ethnicity data and have included the results in the Supplemental Materials. We found some significant effects by race/ethnicity in those analyses. Specifically, Asian students perceived being negatively impacted less often on grades, sense of community and career preparation. Also, Black students reported a positive impact on the amount of time studying more often and multiracial students reported a negative impact on grades more often.

Finally, the indicators of socioeconomic status we used (federal Pell grant eligibility and first-generation status) are coarse measures that do not capture socioeconomic status accurately. However, these were the only indicators that we could access from the university registrar.

Beyond COVID-19: preparing for the next emergency.

Instructors responded with greater flexibility in grading in response to the rapid transition to remote learning in Spring 2020 and students received higher grades on average. This shows that instructor response was effective in preventing grade declines for students and doing so equitably across the student population. However, student perceptions of the Spring 2020 semester were less positive, including a sense of diminished learning, loss of community, and reduced career preparation. Even if students' perception of their learning is not accurate, perceived learning losses might still have important effects on students' confidence in the course content or interest in pursuing a career in biology. Similar learning losses may have occurred in the Fall 2020 semester and Spring 2021 as the COVID-19 pandemic continued to spread in the US and worldwide.

As we look ahead, these students affected by the pandemic may need more support in subsequent courses, especially in courses that build on prior learning. Dedicating class time to reminding students of important concepts at the beginning of each course or course module could be one form of support. However, upper-level courses may not have class time to spare, so adding supplemental tutorials or instruction may be an alternative way to counteract these potential learning deficits of pre-requisite knowledge. Further, the loss of feeling a part of the biology community needs to be addressed. More intentional community building exercises in classes or in the larger department outside of classes could be ways to heal the damage to students' sense of belonging.

Although COVID-19 may only affect college education for a particular timeframe, it is important to garner lessons from this experience to prepare for the next emergency, which could be global such as a pandemic, or local such as a natural disaster. Building robust networks of communication among students, instructors, and staff members, and offering greater training and support for online teaching for instructors are steps that could help us prevent some of the challenges associated with the rapid transition to remote learning experienced during the COVID-19 pandemic. We hope that some of the flexibility afforded to students during the pandemic is carried on even after in-person courses resume as instructors may have a better understanding of the myriad of challenges that college students experience daily. Lastly, as the COVID-19 pandemic reminded us, our classrooms and universities do not exist in isolation and are a part of the larger society and therefore, affected by the larger societal forces and power structures that impact student learning in our institutions. Therefore, we must continue to strive toward social justice inside and outside our higher education institutions.

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1071 Supporting Information

1072 **S1 File. Instructor survey.docx** Instructor survey questions analyzed in this study.

1073 **S2 File. Student survey.docx** Student survey questions analyzed in this study.

1074 **S1 Table. Number of students in the courses analyzed for the grades data.**

1075 **S2 Table. Regression model specifications.** Model 1 estimates the Spring 2020 effect and its
1076 interaction with instruction mode. Model 2 extends Model 1 to consider the possibility of
1077 demographic interaction effects. Model 3 estimates the predictive value of instructors' reported
1078 course changes on the Spring 2020 grade shift as compared to the same course in Spring
1079 2018/19.

1080 **S3 Table. Linear regression results for courses in in-person and online degree program.**
1081 This model shows interaction effects among each demographic category and the COVID-19
1082 semester.

1083 **S4 Table. Changes in assessment practices.** Frequency at which instructors chose various
1084 options regarding changes made to their assessment practices following the transition to remote
1085 learning in Spring 2020.

S5 Table. Ordinal regression results for the perceived impact of the transition to remote learning on students. Ordinal regression output with survey items about impact on students as the outcomes and demographics as predictors.

S6 Table. Ordinal regression results for the perceived impact of the transition to remote learning on student interactions. Ordinal regression output with survey items about impact on time spent studying and interactions as the outcomes and demographics as predictors.

S7 Table. Ordinal regression results for perceived impact on students with disaggregated race/ethnicity data. Ordinal regression output with survey items about impact on students as the outcomes and demographics as predictors with disaggregated race/ethnicity data.

S8 Table. Ordinal regression results for perceived impact on student interactions with disaggregated race/ethnicity data. Ordinal regression output with survey items about impact on time spent studying and interactions as the outcomes and demographics as predictors with disaggregated race/ethnicity data.

S9 Table. Impact on grades, learning and career preparation. Full distribution of Likert scale responses on the student survey on the perceived impact of the transition to remote learning in Spring 2020 on grades, learning and career preparation.

S10 Table. Impact on interest in biology major, interest in learning science and sense of community. Full distribution of Likert scale responses on the student survey on the perceived impact of the transition to remote learning in Spring 2020 on interest in biology major, interest in learning science and sense of community.

S11 Table. Impact on time spent studying and interacting with others. Full distribution of Likert scale responses on the student survey on the perceived impact of the transition to remote learning in Spring 2020 on time spent studying and interacting with others.

S12 Table. Pell-eligible and students who worked a job in the student survey dataset.

S1 Figure. Distribution of student responses about instructional practices. Blue points indicate the option that the instructor for the course chose.

S2 Figure. Distribution of student responses on perceived impact of transition to remote learning on grades by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their grades. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S3 Figure. Distribution of student responses on perceived impact of transition to remote learning on learning by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their learning. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S4 Figure. Distribution of student responses on perceived impact of transition to remote learning on interest in biology major by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their interest in biology major. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S5 Figure. Distribution of student responses on perceived impact of transition to remote learning on interest in learning about scientific topics by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their interest in learning about scientific topics. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S6 Figure. Distribution of student responses on perceived impact of transition to remote learning on feeling a part of the biology community at the university by social identities.

Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their feeling a part of the biology community at the university. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S7 Figure. Distribution of student responses on perceived impact of transition to remote learning on career preparation by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their career preparation. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S8 Figure. Distribution of student responses on perceived impact of transition to remote learning on amount of time spent studying by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their amount of time spent studying. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

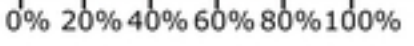
S9 Figure. Distribution of student responses on perceived impact of transition to remote learning on amount of time spent interacting with instructors by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their amount of time spent interacting with instructors. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S10 Figure. Distribution of student responses on perceived impact of transition to remote learning on amount of time interacting with other students in class by social identities.

Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their amount of time spent interacting with other students in class. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

S11 Figure. Distribution of student responses on perceived impact of transition to remote learning on amount of time interacting with other students outside of class by social identities. Bar plot showing student responses by gender, race/ethnicity and socioeconomic status on the perceived impact of the transition to remote learning in Spring 2020 on their amount of time spent interacting with other students outside of class. BLNP refers to Black, Latinx, Native American, and Pacific Islanders. Pell eligibility and college generation status are included as proxies for socioeconomic status.

Survey Item	% students reporting negative effect	Demographic differences
Impact on grades	55.8	No differences
Impact on learning	69.1	Women reported negative impact more often
Interest in biology major	31.5	No differences
Interest in learning science	37.1	No differences
Feeling like a part of University biology community	66.9	No differences
Impact on career preparation	67.1	Women reported negative impact more often
	% students reporting decrease in time	**Demographic differences**
Time spent studying	41.2	No differences
Time spent with instructors	88.7	BLNP students reported decrease less often
Time spent in class with students	84.9	Pell-eligible students reported decrease more often
Informal time with students	77.7	No differences



Figure