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Grades and Grade Anomalies Before, During, and After Remote COVID-19 Instruction for First-year Engineering Majors: Overall Trends and Gender Inequities*

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In this research we use grades and "grade anomalies" to investigate student performance before, during, and after the period of COVID-19 remote instruction in courses for first-year engineering majors. We also use these measures to investigate gender equity in these courses. We define grade anomaly as the difference between a student's grade in a course under consideration and their grade point average (GPA) in all other classes thus far. If the grade in a class is lower than a student's GPA, we say they have a "grade penalty", and if it is higher we say they have a "grade bonus". We investigated all required courses for this group of students and found that the Engineering and English Composition courses tended to have grade bonuses, while Mathematics, Physics, and Chemistry courses tended to have grade penalties. We broadly find that both grades and grade penalties showed positive trends during remote instruction and deteriorated after remote instruction. We also find that there were many more gender differences in grade anomalies than in grades. We hypothesize that women's decisions to pursue STEM careers may be affected more by the grade penalty received in required science courses than men's because their grade penalties are often larger during all time periods studied. Furthermore, the grade penalty measure can be easily computed by institutions concerned with equity.

Keywords: gender; equity; grades; grade penalty; grade anomaly; remote instruction; COVID-19

1. Introduction and Theoretical Framework

Remote teaching due to the COVID-19 pandemic has inspired research assessing the differences between online and in-person courses regarding student learning outcomes and classroom equity [1–5]. There are mixed findings regarding the effect of online instruction on student learning [1, 6]. In this study, we explore overall trends in both grades and grade anomalies before, during, and after the period of remote instruction due to COVID-19 in courses for first-year engineering students in a large public university.

We define grade anomaly as the difference between a student's grade in a course of interest and their grade point average (GPA) in all other classes up to that point. The mean of this statistic for all students who took a course is the average grade anomaly (AGA). We divide average grade anomalies into "bonuses" and "penalties". A course in which students on average earn a lower grade than usual has an AGA with grade penalty, while a course in which students on average earn a higher grade than usual has an AGA with grade bonus.

Within our framework, we posit that grade anomaly may allow us to track, through institutional grade data, an important measure of how courses may affect students' academic self-concept. Academic self-concept is a relatively stable measure of a students' perceived ability to succeed in the academic sphere, and is based on grades and outside feedback (e.g., from parents, peers, and instructors) [7–10]. Grades inform academic self-concept as both an external ("How good at math am I compared to other students?") and internal ("How good am I at math compared to English?") frame of reference [7–9]. While academic self-concept is generally quite stable, it can change quite quickly during periods of transition (such as the transition from high school to university) [8].

Our framework uses grade penalty as a central construct instead of grade because students' academic self-concept is often based on comparisons, not absolute grades [10]. Students may compare their grades across courses to determine which disciplines they excel at or struggle with [10]. Additionally, students tend to have a fairly fixed view of what "kind" of student they are, e.g., students may endorse the idea that "If I get As, I must be an A kind of person. If I get a C, I am a C kind of person" [11]. Grade anomalies may challenge or reinforce students' ideas about what kind of student they are, and if they are capable of succeeding in their chosen major. Many students who leave STEM majors explicitly cite lower grades than they are used to as a reason for doing so [11, 12]. Grade penalties are more common and extreme

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in STEM disciplines than in humanities or social science departments [11, 13–15].

Additionally, we aim to investigate gender differences in grades and AGAs. When women leave STEM disciplines, they often do so with higher grades than men who remain in the program [12, 16–18]. Women are more underrepresented in engineering than in many other STEM disciplines [1, 19–25], so focusing on retention is particularly important for this field. If women are leaving engineering programs with grades that meet or exceed minimum requirements [11, 12], it is likely that many students who would succeed in engineering careers will pursue other professional paths.

Broadly, in this research we aim to understand differences in students' grade anomalies before, during, and after the period of remote instruction due to COVID-19 with a particular focus on gender differences in grades and grade anomalies. This will build on previous work which observed grade anomalies at this same institution for over ten years pre-COVID [26–28].

2. Research Questions

We focus on first-year engineering majors and aim to answer the following research questions regarding grade anomalies:

RQ1. Do grades or grade anomalies differ between before, during, and after the period of remote COVID teaching?

RQ2. Are there gender differences in grades or grade anomalies, and do they differ between the periods before, during, and after COVID-19 remote instruction?

3. Methodology

3.1 Participants

Participants in this study were enrolled in engineering majors at a large, public, and urban institution. Grade data were collected over four years. We divide these semesters into three groups, which are described in Table 1. We excluded courses that were taken during the summer semester. We excluded summer courses because they are not a typical representation of courses at our institution. For example, many summer students do not primarily attend our institution, but are local students visiting home for the summer. In addition, the class sizes are an order of magnitude smaller than those in the Fall and Spring semesters. This left us with 5,807 pre-remote, 2,775 remote, and 4,065 post-remote instances of an enrollment in a course. For example, a student who takes four courses in one semester and three in the next semester has seven instances of enrollment. Demographic information for the student sample can be found in Table 2. De-identified demographic data were provided through university records.

3.2 Course Selection

At this institution, there is a standardized curriculum for first-year engineering majors. All of these courses were included in this research, with an exception of two pass/fail seminars which do not count towards a students' grade point average. This included a total of ten courses, which are described in Table 3.

3.3 Measures

3.3.1 Course Grade

Course grades were based on the 0–4 scale used at our university, and a conversion of letter grades to GPA points can be seen in Table 4. We are unable to report grading schemes of each instructor, type of course (i.e., traditional lectures or active learning), or any other detailed course-level information due to the large number of courses sampled.

3.3.2 Grade Anomaly (GA)

GA was found by first finding each student's grade

Table 1. Labels for each time period studied

Label	Period
Pre-Remote	Four semesters of in-person instruction before the COVID-19 pandemic, excluding Spring 2020
Remote	Two semesters of remote instruction due to the COVID-19 pandemic, excluding Spring 2020
Post-Remote	Two semesters of in-person instruction after the return to in-person classes

Table 2. Demographic information for study participants. Several survey options for ethnicity were excluded because they each made up less than 0.5% of the sample. These groups are Indigenous American, Pacific Islander, Not Specified, and Other. Unknown indicates that a student did not submit a response to the item, while Not Specified indicated that they chose the option "I prefer not to specify"

	Sex		Race/Ethnicity					
Group	Female	Male	Asian	Black	Latine	Multiracial	White	Unknown
Pre-Remote	36%	64%	11%	4%	6%	5%	74%	1%
Remote	36%	64%	9%	5%	6%	6%	72%	1%
Post-Remote	31%	69%	17%	4%	6%	5%	65%	2%

Table 3. Courses engineering majors were required to take during their first year, along with which department/school offered the course and a description of the course. Students typically took Physics 1, Chemistry 1, Calculus 1, Engineering Analysis (Eng. Analysis), and Composition Seminar (Comp. Seminar) during their first Fall semester. Students typically took Physics 2, Chemistry 2, Calculus 2, Engineering Computing, and Engineering Communication (Eng. Comm.) during their first Spring semester. Engineering Communication was not offered until Spring of 2020, so there is no Pre-Remote data for this course

Course Title	Department	Description
Physics 1	Physics	*Calculus*-based, covered mechanics and waves
Physics 2	Physics	Calculus-based, covered electricity, magnetism, circuits, electromagnetic theory and optics
Chemistry 1	Chemistry	Only for engineering students. Covered stoichiometry, the properties of solids, liquids and gases, thermochemistry and the electronic structure of atoms and molecules.
Chemistry 2	Chemistry	Only for engineering students. Covered solutions, thermodynamics, kinetics, chemical equilibrium, coordination chemistry, redox reactions and nuclear chemistry.
Calculus 1	Mathematics	Covered derivative and integral of functions of one variable and their applications.
Calculus 2	Mathematics	Covered calculus of transcendental functions, techniques of integration, series of numbers and functions, polar coordinates, and conic sections
Eng. Analysis	Engineering	Covered an introduction to Excel and an introduction to design and entrepreneurship.
Eng. Computing	Engineering	Covered basic programming skills using MATLAB and C.
Comp. Seminar	English	Course in which students wrote about the disciplines, practices, methods, ethics, and education of engineering.
Eng. Comm.	English	Students researched and wrote about a single topic regarding a current engineering innovation or technology in the format of a conference paper.

Table 4. Grades and GPA points for this university's grading standards. For most majors, a C or above is a passing grade. A C was the minimum grade needed to pass a course at this institution for all majors included.

Grade	A+/A	A–	B+	B	B–	C+	C	C–	D+	D	D–	F
GPA Value	4.00	3.75	3.25	3.00	2.75	2.25	2.00	1.75	1.25	1.00	0.75	0.00

point average excluding the course of interest (GPA_{exc}). This was done by using the equation

$$GPA_{exc} = \frac{(GPA_c \times Units_c) - (Grade \times Units)}{Units_c - Units} \quad (1)$$

where GPA_c is the student's cumulative GPA, $Units_c$ is the cumulative number of units (also called credit hours) the student has taken, *Grade* is the grade the student received in the course of interest, and *Units* is the number of units associated with the course of interest. After finding GPA_{exc} we can calculate grade anomaly (GA) by finding the difference between a student's GPA_{exc} and the grade received in that class:

$$GA = GPA_{exc} - Grade. \quad (2)$$

A negative GA corresponds to a course grade lower than a students' GPA in other classes and we call this a "grade penalty". A positive GA corresponds to a course grade higher than a students' GPA in other classes and we call this a "grade bonus". Average grade anomaly (AGA) is the mean of students' grade anomalies (GA) for each course, and is the metric by which we compare courses.

3.4 Analysis

To characterize both average grade anomaly (AGA) and grades, we found the sample size, mean, standard deviation, and standard error of each measurement for each course of interest. We calculated these statistics for women and men separately, and then for all students combined. We also compared the effect size of gender on both grade and grade anomaly, using Cohen's *d* to describe the size of the mean differences and unpaired *t*-tests to evaluate the statistical robustness of the differences. Cohen's *d* is calculated as follows:

$$d = \frac{\mu_1 - \mu_2}{\sqrt{(\sigma_1^2 + \sigma_2^2)/2}} \quad (3)$$

where μ_1 and μ_2 are the means of the two groups σ_1 and σ_2 are the standard [28]. Cohen's *d* is considered small if $d \sim 0.2$, medium if $d \sim 0.5$, and large if $d \sim 0.8$ [29]. We used a significance level of 0.05 in the *t*-tests and as a balance between Type I (falsely rejecting a null hypothesis) and Type II (falsely accepting a null hypothesis) errors [30]. All analysis was conducted using R [31].

4. Results

4.1 Chemistry Courses

Chemistry courses had the lowest grades of the courses studied during the pre-remote, remote, and post-remote periods, which can be seen in Figs. 1 and 2 as well as Tables A1 and A2 in the Appendix. For Chemistry 1 and 2, grades as well as

Table 5. Means and standard deviations (SD) of grades and grade anomalies by gender for courses offered by the Chemistry Department. Cohen's *d* is positive if men had higher grades or smaller AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

		Women					Men					Cohen's *d*	
			AGA		Grade			AGA		Grade			
Course	Type	N	Mean	SD	Mean	SD	N	Mean	SD	Mean	SD	AGA	Grade
Chemistry 1	Pre-Remote	234	–0.83	1.17	2.5	1.00	418	–0.77	1.01	2.47	0.99	0.05	–0.03
	Remote	79	–0.74	0.74	2.53	0.91	167	–0.75	0.73	2.46	0.92	–0.01	–0.07
	Post-Remote	106	–1.11	1.41	2.23	1.25	257	–0.91	0.96	2.25	1.15	0.18	0.01
Chemistry 2	Pre-Remote	148	–0.74	0.55	2.39	0.77	292	–0.73	0.59	2.34	0.87	0.02	–0.06
	Remote	70	–0.6	0.52	2.63	0.80	135	–0.75	0.63	2.41	0.87	–0.25	0.26
	Post-Remote	82	–0.81	0.62	2.27	0.94	205	–0.83	0.69	2.24	1.05	–0.04	–0.03

Table 6. Means and standard deviations (SD) of grades and grade anomalies by gender for courses offered by the Engineering School – Engineering Analysis (Eng. Analysis) and Engineering Computation (Eng. Comp). Cohen's *d* is positive if men had higher grades or smaller AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

		Women					Men					Cohen's *d*	
			AGA		Grade			AGA		Grade			
Course	Type	N	Mean	SD	Mean	SD	N	Mean	SD	Mean	SD	AGA	Grade
Eng. Analysis	Pre-Remote	320	0.36	0.53	3.43	0.57	531	0.36	0.6	3.37	0.6	0.01	0.1
	Remote	132	0.42	0.48	3.53	0.65	212	0.45	0.45	3.47	0.64	0.08	–0.09
	Post-Remote	156	0.4	0.72	3.28	0.82	322	0.45	0.62	3.33	0.76	0.08	0.07
Eng. Comp.	Pre-Remote	231	0.1	0.79	3.15	0.92	439	0.22	0.73	3.23	0.8	0.15	0.1
	Remote	103	–0.06	0.57	3.1	0.78	187	0.03	0.62	3.15	0.82	0.15	0.06
	Post-Remote	126	–0.14	0.74	2.89	0.98	289	0.08	0.71	3.06	0.94	0.29*	0.17

Table 7. Means and standard deviations (SD) of grades and grade anomalies by gender for courses offered by the English Department – Composition Seminar (Com. Sem.) and Engineering Communication (Eng. Comm.). Cohen's *d* is positive if men had higher grades or smaller AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

		Women					Men					Cohen's *d*	
			AGA		Grade			AGA		Grade			
Course	Type	N	Mean	SD	Mean	SD	N	Mean	SD	Mean	SD	AGA	Grade
Com. Sem.	Pre-Remote	161	0.59	0.79	3.68	0.58	281	0.34	0.74	3.42	0.77	–0.33**	–0.36***
	Remote	138	0.57	0.6	3.67	0.53	223	0.43	0.53	3.45	0.55	–0.25*	–0.39***
	Post-Remote	164	0.62	0.81	3.48	0.81	347	0.43	0.9	3.36	0.83	–0.21*	–0.14
Eng. Comm.	Remote	104	0.75	0.54	3.83	0.3	191	0.73	0.6	3.78	0.37	–0.03	–0.17
	Post-Remote	126	0.67	0.63	3.62	0.43	284	0.64	0.67	3.59	0.43	–0.05	–0.08

Table 8. Means and standard deviations (SD) of grades and grade anomalies by gender for courses offered by the Mathematics Department. Cohen's d is positive if men had higher grades or smaller AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

		Women					Men					Cohen's *d*	
			AGA		Grade			AGA		Grade			
Course	Type	N	Mean	SD	Mean	SD	N	Mean	SD	Mean	SD	AGA	Grade
Calculus 1	Pre-Remote	216	–0.22	1.45	2.97	0.99	365	–0.28	1.43	2.85	1	–0.04	–0.12
	Remote	94	–0.56	1.11	2.74	0.82	148	–0.43	1.02	2.76	0.95	0.12	0.01
	Post-Remote	155	–1.21	2.31	2.21	1.33	310	–0.68	1.42	2.35	1.22	0.30*	0.11
Calculus 2	Pre-Remote	209	–0.55	1.06	2.61	1.16	395	–0.54	0.98	2.57	1.07	–0.01	–0.03
	Remote	78	–0.31	0.51	2.96	0.68	133	–0.15	1.00	3.05	0.78	0.19	0.11
	Post-Remote	92	–0.41	0.83	2.71	1.05	231	–0.61	1.05	2.51	1.22	–0.2	–0.17

grade anomalies were similar before and during remote instruction. However, during post-remote instruction, average course grades (see Fig. 1) and the magnitude of the grade penalty (see Fig. 2) increased. Before and during remote instruction the average grade for Chemistry 1 was between a C+ and B– (2.48 for both), which dropped to a C+ (2.24) for post-remote instruction. Before and during remote instruction the average grade for Chemistry 2 was also between a C+ and B– (2.36

Table 9. Means and standard deviations (SD) of grades and grade anomalies by gender for courses offered by the Physics Department. Cohen's d is positive if men had higher grades or smaller AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

		Women					Men						
			AGA		Grade			AGA		Grade		Cohen's *d*	
Course	**Type**	**N**	**Mean**	**SD**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Mean**	**SD**	**AGA**	**Grade**
Physics 1	Pre-Remote	376	–0.84	0.94	2.49	0.77	573	–0.51	1.03	2.71	0.86	0.33***	0.27***
	Remote	127	–0.32	0.64	2.94	0.71	209	–0.12	0.63	3	0.7	0.32*	0.09
	Post-Remote	180	–0.95	1.55	2.36	1.03	351	–0.45	1.05	2.66	1.03	0.40***	0.29**
Physics 2	Pre-Remote	198	–0.67	0.55	2.59	0.74	416	–0.39	0.6	2.8	0.82	0.48***	0.27**
	Remote	87	–0.28	0.54	3.04	0.73	157	–0.34	0.69	2.93	0.81	–0.09	–0.15
	Post-Remote	88	–0.61	0.5	2.72	0.74	219	–0.42	0.56	2.76	0.81	0.35**	0.05

and 2.49, respectively), which also dropped to a C+ (2.24) for post-remote instruction.

Chemistry courses also had the largest grade penalties during the pre-remote, remote periods, which can be seen in Fig. 2. Excluding Calculus 1, they also had the largest grade penalties in the post-remote period. Chemistry 1 had slightly larger grade penalties than Chemistry 2. Students taking Chemistry 1 could expect a grade approximately three-fourths of a letter grade lower than their overall GPA before and during remote instruction, and a full letter grade after remote instruction. Students could generally expect a grade three-fourths of a letter grade lower than their other courses for all time periods studied. Table 5, as well as Figs. 3 and 4 shows that neither chemistry course had any statistically significant difference between men's and women's grades or average grade anomalies.

4.2 Engineering Courses

Generally, courses offered by the Engineering School had the highest grades of all STEM courses, and were the only STEM courses that had a grade bonus (or a grade anomaly of almost 0) rather than grade penalty which can be seen in Figs. 1 and 2 as well as Tables A1 andA2 in the Appendix. For Engineering Analysis, average grades increased slightly from pre-remote to remote instruction and decreased slightly from remote to post-remote instruction, though the average grade remained between a B+ and A– during all three time periods. Fig. 2 reveals that, on average, students tended to have a grade bonus of almost half a letter grade.

For Engineering Computing, average grades dropped slightly from pre-remote to remote instruction and again from remote to post-remote instruction (see Fig. 2 and Table A2). However, the average grade remained between a B and B+ throughout. Before remote instruction, students tended to have a slightly higher grade in Engineering Computing than their average, but during and after remote instruction there was no grade anomaly in this course.

There were generally no statistically significant grade or average grade anomaly differences between men and woman in these courses, which can be seen in Table 6, as well as Figs. 3 and 4. One exception was average grade anomaly during post-remote courses, in which men had a small grade bonus and women had a small grade penalty.

4.3 English Courses

Courses offered by the English Department were the only non-STEM courses included in this study, and Figs. 1 and 2 show that they also tended to have the highest grades and largest grade bonuses of all the courses included in this research. The average grade for Composition Seminar was between a B+ and A– throughout, though the average course grade was slightly lower during post-remote instruction than pre-remote or remote instruction. During all three periods, students on average had a grade half of a letter grade higher in Composition Seminar then in their other courses (see Fig. 2).

There is no pre-remote instruction data for Engineering Communication because the class did not exist yet. However, Fig. 1 shows that the average grade during remote instruction was the highest of any course studied: an A– (3.80). During post-remote instruction, the average grade decreased slightly to 3.60. Composition Seminar had the largest graded bonuses of all the courses, and students generally had almost three-fourths of a letter grade higher in this course than in their other courses during remote and post-remote instruction (see Fig. 2).

There is no pre-remote instruction data for Engineering Communication because the class did not exist yet. However, Fig. 1 shows that the average grade during remote instruction was the highest of any course studied: an A– (3.80). During post-remote instruction, the average grade decreased slightly to 3.60. Composition Seminar had the largest graded bonuses of all the courses, and students generally had almost three-fourths of a letter grade higher in this course than in their other courses during remote and post-remote instruction (see Fig. 2).

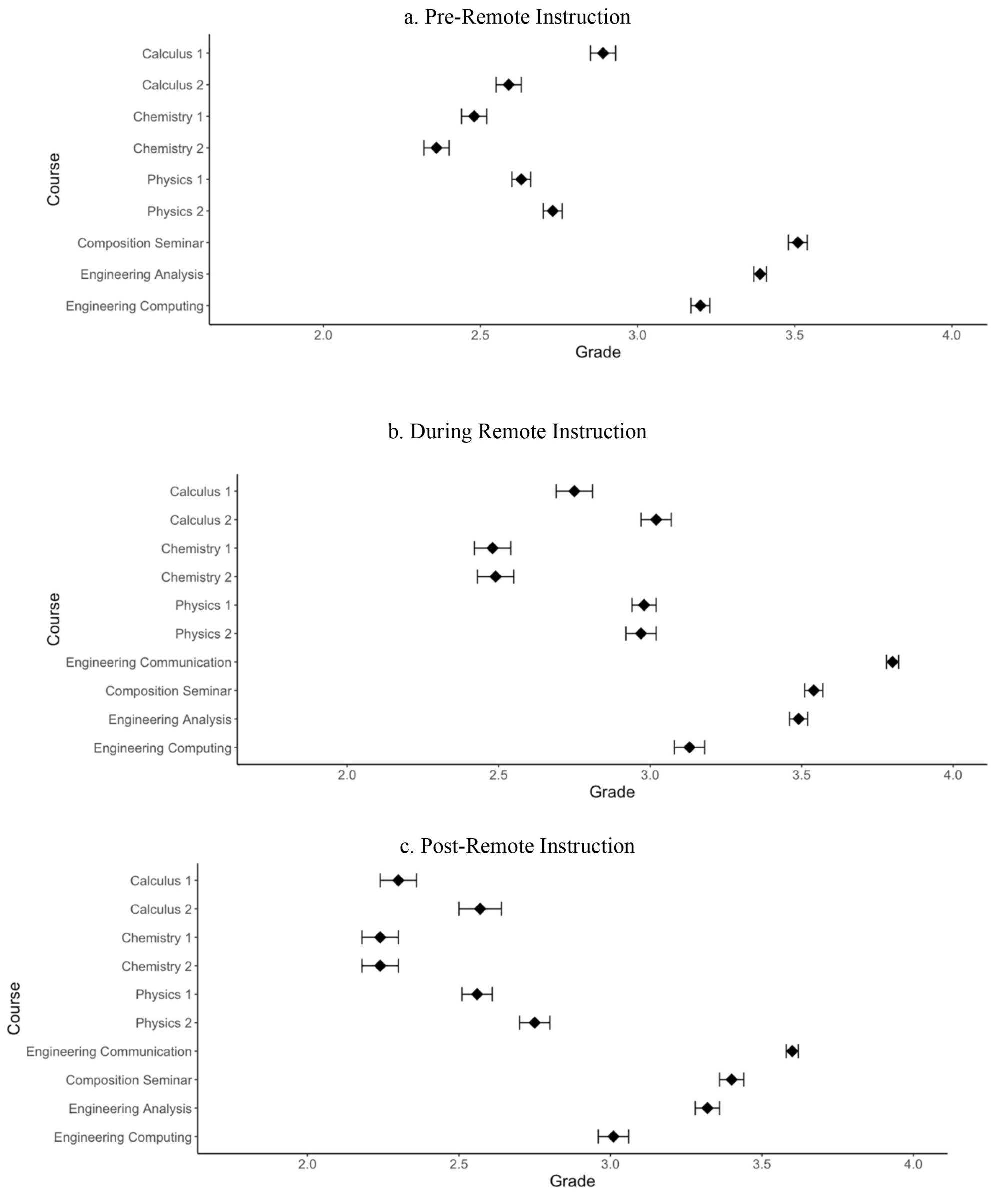

Fig. 1. Comparison of student grades for each course of interest for classes during pre-remote instruction (a), during remote instruction (b), and during post-remote instruction (c). Ranges represent standard error of the mean.

In Composition Seminar, Table 7 shows that there were statistically significant gender differences in both grades and grade anomalies. As seen in Figs. 3 and 4, before and during remote instruction, women tended to have higher grades and larger grade bonuses than men, and after remote instruction women had larger average grade bonuses (but not grades) than men. There were no statistically significant grade or average grade anomaly differences between men and women for Engineering Communication either during or after remote instruction which can be seen in Table 7.

4.4 Mathematics Courses

Unlike courses offered by other departments, the courses in the Mathematics department, Calculus 1 and 2, did not follow similar trends. Figs. 1 and 2 reveal that the average grade in Calculus 1 went from approximately a B– during the pre-remote and remote periods, and dropped to a C+ during the post-remote period. Though the average letter grade was the same during the pre-remote and remote periods, the average grade in Calculus 1 decreased from pre-remote to remote instruction. Concerningly, Calculus 1 was the only course in which the average grade consistently decreased from pre-remote to remote to post-remote courses. On the other hand, the average Calculus 2 grade was between a C+ and B– during the pre-remote period, rose to a B during remote teaching, and fell back to a 2.30 during the post-remote period. This was a common trend among the overall set of

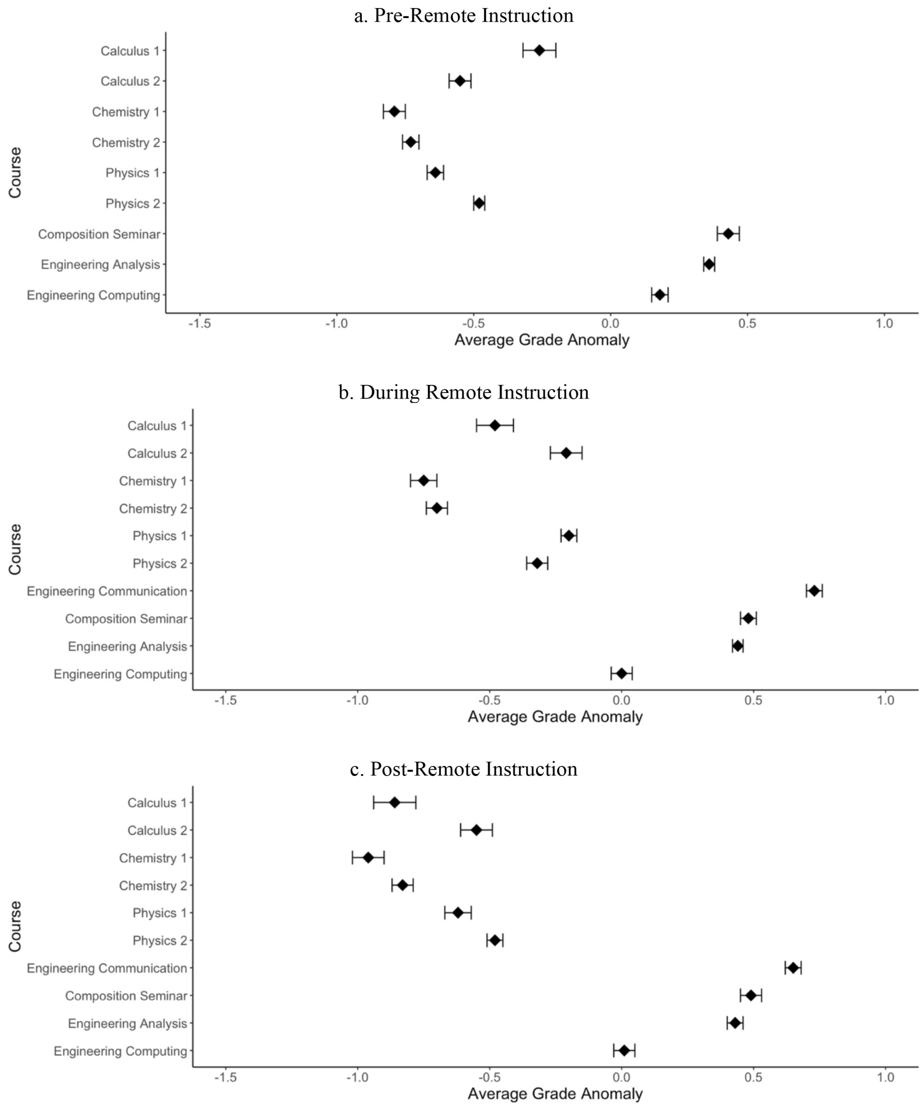

Fig. 2. Comparison of student grade anomalies for each course of interest for classes during pre-remote instruction (a), during remote instruction (b), and during post-remote instruction (c). Ranges represent standard error of the mean.

courses (see Fig. 1): grades were similar during the pre- and post-remote periods, but slightly higher during the remote period.

Regarding AGAs, Fig. 2 shows that Calculus 1 had a comparatively small grade penalty compared to other courses during the pre-remote period. However, the AGA for Calculus 1 increased in magnitude for each period. In fact, Calculus 1 had the largest grade penalties aside from the Chemistry courses during remote and post-remote instruction. Calculus 2 consistently had AGAs that were not particularly high or low compared to other courses studied. The average grade penalty in Calculus 2 was identical during the pre- and post-remote periods, but was smaller during the remote period.

There were no statistically significant gendered grade differences in either Mathematics course during any period studied, which can be seen in Table 8, as well as Figs. 3 and 4. There was a gender difference in AGA in Calculus 1 during the post remote period, with women having larger average grade penalties than men. Aside from this, there were no gendered differences in AGAs.

4.5 Physics Courses

Fig. 1 and Table A1 show that Physics 1 letter grades increased from pre to during, but then decreased again during post. In Physics 1, grades went from a B– during pre-remote courses to a B during remote instruction to between a C+ and B– during Post-Remote instruction. Physics 2 letter grades increased from a B– to a B from pre-remote to remote teaching. However, instead of decreasing again during post-remote instruction, the grades remained consistent, and the average grade during post-remote instruction was also a

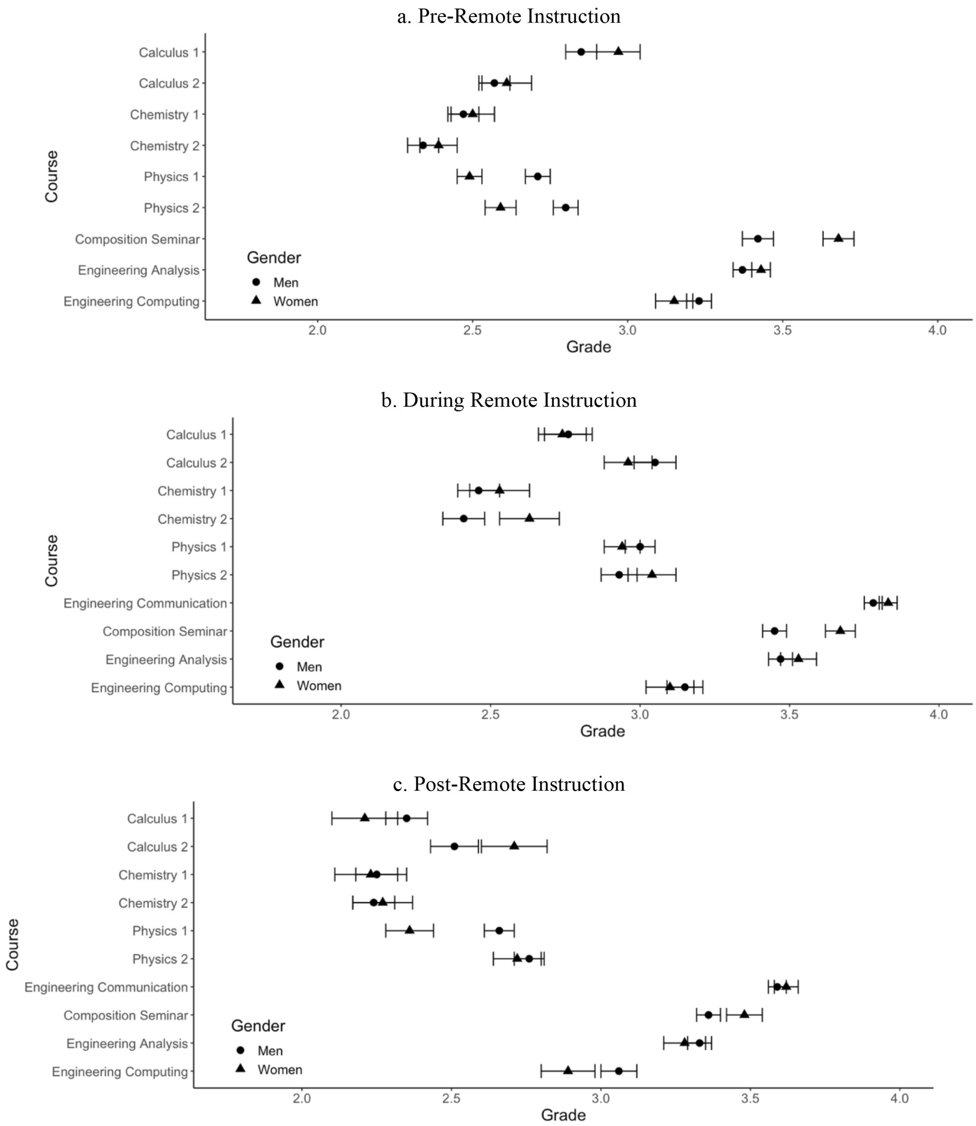

Fig. 3. Comparison of student grades for men and women for each course of interest for classes during pre-remote instruction (a), during remote instruction (b), and during post-remote instruction (c). Ranges represent standard error of the mean.

B–. Physics 1 and 2 average grade penalties followed similar trends. Both had similar AGAs during pre- and post-remote instruction, and had smaller AGAs during remote instruction.

Courses offered by the physics department tended to have more gender differences in both grades and AGAs than courses offered by other departments, which can be seen in Table 9. During pre-remote instruction both Physics 1 and 2 had gendered grade differences. In both cases, men on average had higher grades than women, with a small effect size for both courses (d $\sim$ 0.2). There were also gendered grade differences in Physics 1 grades during post-remote instruction which were similar in magnitude to pre-remote gender differences. There were gender differences in AGAs for both Physics courses during almost all periods, as shown in Table 9. Physics 1 had a small gender differences (d $\sim$ 0.2) during pre-remote and remote courses, and had medium gender differences (d $\sim$ 0.5) during post-remote instruction. Physics 2 had medium (d $\sim$ 0.5) AGA gender differences during pre-remote instruction and small-to-medium (d $\sim$ 0.2 to 0.5) gender differences during post-remote instruction.

5. Discussion

5.1 Do grades or grade anomalies differ between before, during, and after the period of remote COVID teaching?

Grades are important to students for a variety of reasons such as continuing their major, scholarship requirements, graduate school or professional

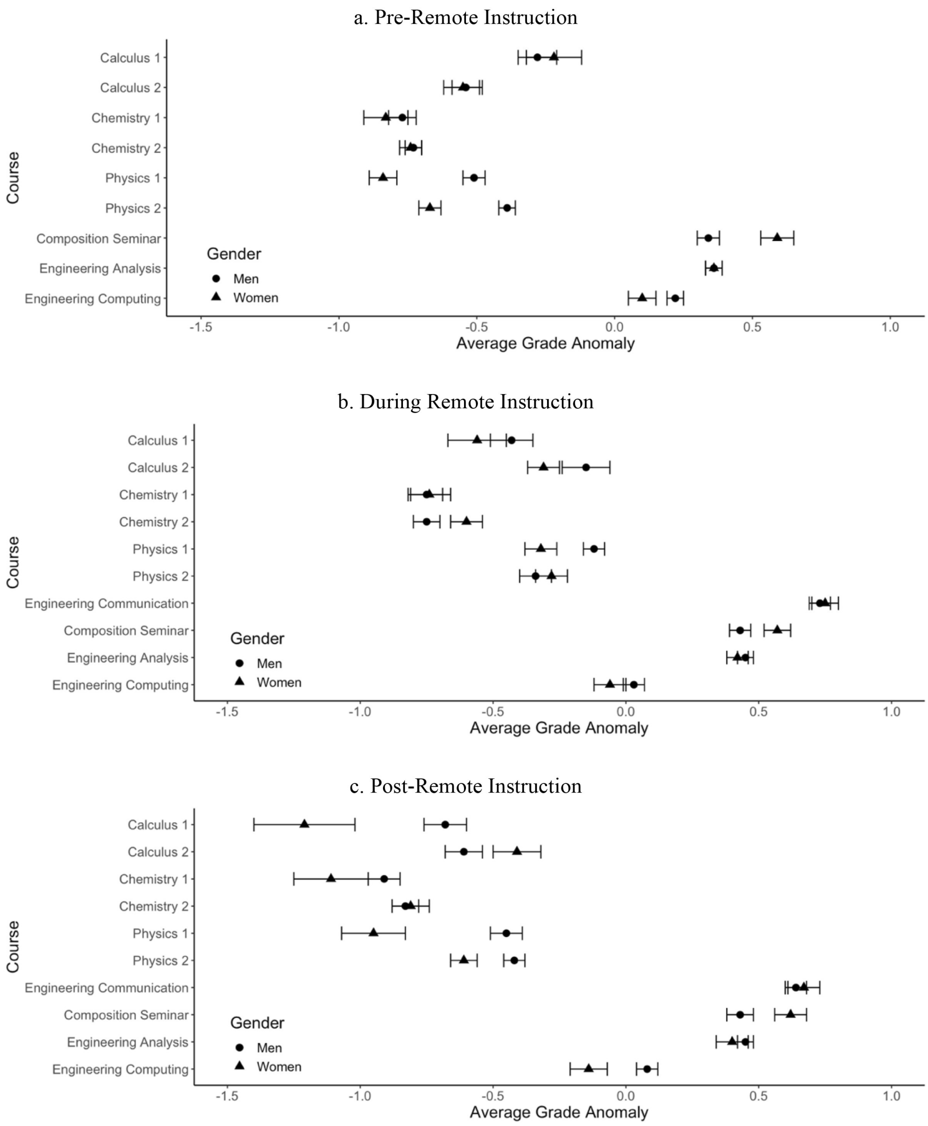

Fig. 4. Comparison of grade anomalies for men and women for each course of interest for classes during pre-remote instruction (a), during remote instruction (b), and during post-remote instruction (c). Ranges represent standard error of the mean.

school admissions, and career goals. In general, grades were higher during remote instruction than they were during pre-remote instruction, and then decreased after remote instruction. During remote instruction, grades tended to be a fraction of a letter grade higher than during pre- or post-remote instruction (for example, the mean Calculus 2 grade was C+ during pre-remote instruction, B– during remote instruction, and a C+ during post-remote instruction). These increases in grades may be due to a range of factors. For example, grading schemes and assessment types may have been changed, or instructors may have been more flexible for students than during pre-remote classes [32] (Chan 2021).

Broadly, grades were higher during remote instruction and were lower again during post-remote instruction but there were some courses that did not follow this trend. Two of those courses will not be discussed here because they had higher grades compared to most courses in this study. On the other hand, Chemistry 1, Chemistry 2, and Calculus 1 had concerning trends in grades. Namely, Chemistry 1 and 2 had the lowest overall grades of the courses studied during all periods studied: both had a C average post-remote grade. Calculus 1 had the largest decrease in average grade of any course over time – from pre- to post-remote, the average grade dropped from a 2.89 to a 2.30 on a 4-point scale.

AGAs, unlike grades, do not have a direct effect on students' outcomes such as scholarships and graduate admissions. A student with an A average who receives a B in a class has the same grade anomaly as a student with a B average who receives a C in the class. Here, we use the idea of academic self-concept from Situated Expectancy Value Theory to frame how students may think about grade anomalies [8]. AGAs may challenge a student's idea about what kind of student they are (i.e. an "A" student or a "C" student) [11]. In particular, students may compare their grades across courses to determine which disciplines they excel at or struggle with [10].

Our results show that there are grade penalties in all Chemistry, Math, and Physics courses studied, while there were either grade bonuses or no grade anomaly in the Engineering and English Composition courses. Other studies that focus on AGA find that science and math courses have large grade penalties, while humanities courses have grade bonuses [11, 13–15]. This aligns with our findings except that engineering courses do not have grade penalties.

Generally, AGAs had a smaller magnitude during remote instruction than pre- or post-remote instruction. That is, generally, students' grades were more consistent during remote instruction, so that most classes deviated less from a student's GPA during remote instruction. This was not true for Calculus 1, Chemistry 1, or Chemistry 2. The Chemistry courses did not have increased average grades during remote instruction as many other courses did, while Calculus 1 actually had lower grades during remote than pre-remote instruction. Throughout the study, Chemistry 1 and 2 had the largest grade penalties.

We hypothesize that smaller grade anomalies may result in students being less concerned that they can succeed in their discipline, and may rely more on other factors (such as interest) to make decisions regarding major and career choice. Grade penalties are more common and larger in STEM disciplines than in social sciences or humanities [11, 13–15], but our findings show that there are significant variations in AGAs even among STEM courses. For example, Chemistry courses tended to have large grade penalties, Engineering courses tended to have grade bonuses, and Physics and Mathematics courses tended to have AGAs in the middle. Thus, AGAs are not a simple issue of STEM courses having larger AGAs than non-STEM courses. Instructors and departments with comparatively lower grades and larger AGAs than others may benefit from pedagogies implemented by other STEM departments and instructors at their institution.

There are likely to be a range of potential factors contributing to differences in grades and AGAs over time. Though there is a possibility that some students are cheating, cheating on exams seems to have only small increases in the USA during the pandemic, though the effect may be larger in other regions [33]. There is also research that suggests that there are specific factors that could lead to increased grades during remote instruction. For example, because there were more low-stakes assessments during remote instruction, students may be more likely to engage in spaced practice instead of "cramming" for assessments during remote learning [6]. One study showed that students had higher grades during COVID-19 remote instruction even on identical assessments that were also given online pre-pandemic [6]. One study that focused on quantum mechanics (an upper-level physics course) found that implementing low-stakes formative assessments instead of exams did not lead to lower scores on course post-test (which only contributed a small amount to the students' final grade) [1]. Though these studies do not specify any specific reason that there may be differences in grades during remote versus in-person classes, they do suggest that increases in grades do not necessarily correlate with lowered academic standards or cheating. Thus, all instructors, including those teaching first-year engineering students, may wish to implement strategies such as low stakes assessments in their courses. In the case of this institution where this investigation was conducted, it may be useful for instructors teaching in the Mathematics and Chemistry Departments to see if any changes made by the Engineering School, English Department, or Physics Department during the transition to online courses and back again may be helpful to their students.

5.2 Are there gender differences in grades or grade anomalies, and do they differ between the periods before, during, and after COVID-19 remote instruction?

During pre-remote instruction, three courses had statistically significant gender differences. For Physics 1 and 2, men had higher grades than women. For Composition Seminar, women had higher grades then men. During remote instruction, only composition seminar had statistically significant grade differences. Again, women had higher grades than men. Finally, during post-remote instruction, men had higher grades than women in Physics 1. Physics 1 gendered grade differences were very similar between pre-remote and post-remote courses.

There were more instances of statistically significant AGA differences than grade differences between men and women. During pre-remote instruction, both Physics courses and Composition Seminar had gender differences. Compared to women, men had smaller grade penalties in Physics

1 and 2 as well as smaller grade bonuses in Composition Seminar. During remote instruction, there were similar trends. Men had smaller grade penalties in Physics 1 and smaller grade bonuses in Composition Seminar, and the effect size of these differences did not change substantially between pre-remote and remote instruction.

The post-remote period had more AGA differences by gender than the other periods. Men had smaller grade penalties than women in Physics 1, Physics 2, and Calculus 1. Women had larger grade bonuses then men in Composition Seminar. In Engineering Computing, men had a small grade bonus and women had a small grade penalty. Broadly, we note that there are more gender differences in AGA than in grades, and that Physics and Composition Seminar had more gender differences in grades and AGAs than other courses. However, because students tend to have grade bonuses in Composition Seminar, we are less worried about this course.

For women in engineering majors, a large grade anomaly in their first Physics course at university may be particularly concerning, and potentially lead them to believe that they do not "have what it takes" to succeed in their major. Women often report worrying more than men that they do not understand the material even if they receive A's, B's, or C's (which are grades that allow students to continue in most programs) [11]. This trend has been found to be particularly strong among high-achieving women [11].

We hypothesize that women may be more likely to have a low academic-self-concept than men at similar performance levels. Prior work has theorized that men are more likely to separate their grades and sense of academic self-concept [11, 12, 34]. Academic self-concept is formed through grades and feedback from outsiders. Women are generally less likely to receive recognition from instructors [35–37], so women may rely more than men on grade information to develop their academic self-concept [11, 12, 34]. Women also tend to earn higher grades than men who have the same standardized test scores [11, 38], so they may be more accustomed to higher grades. As a result, they may have more concern about grades that are lower than what they are accustomed to, especially during the transition from high school to university.

AGAs and raw grade data do not always reveal the same trends: there are many more gender differences in AGA than in grades in the findings presented here. This trend reveals how AGA may be a useful measure. For example, an instructor may not see any gender differences in grades, which is one important indicator of gender equity. However, if they do not know the gender differences in AGA, an instructor or department may not recognize how those grades may be perceived by women and men in their classes. Understanding both grades and AGA differences may allow instructors to understand classroom-level inequities better.

6. Conclusion

In this work we found that courses for first-year engineering majors offered by the Engineering and English departments tended to have grade bonuses while courses offered by the Physics, Mathematics, and Chemistry departments tended to have grade penalties. Generally, grades were higher and grade penalties were smaller during remote instruction compared to pre-remote instruction. During post-remote instruction, grades were lower and grade penalties were larger than during remote instruction. Further, there were more gender differences in both grades and grade penalties (favoring men) during post-remote teaching than for pre-remote or remote teaching.

These results are very important because they provide evidence that courses in STEM departments tend to have grade penalties, and that these penalties decreased during remote instruction. Additionally, AGA may also act as a useful measure of academic self-concept that is easy for institutions to access. Thus, all those responsible for first-year engineering majors should reflect on these findings and consider strategies for mitigating grade penalties observed.

7. Limitations, and Future Research

Although we have evidence of grade penalties in the studied courses as well as gendered grade anomaly differences, we did not have access to syllabi or other information about individual courses offered over the period of data collection. Therefore, we are not able to pinpoint specific practices that may lead to grade penalties, grade bonuses, or gender inequities at our institution.

Finally, this research is based at a primarily white, large, public research university in the USA. While our results may generalize to similar institutions, we do not know what patterns of grade anomalies exist at smaller liberal arts colleges, minority-serving institutions, or community colleges in the US. Additionally, it may also be useful to repeat similar research in other countries, as many countries worldwide were affected differently by the COVID-19 pandemic.

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Appendix

Table A1. Course grades before the COVID-19 Pandemic, during remote classes due to COVID-19, and after the return to in-person instruction. Mean and standard deviation (SD) of average grades, as well as number of students (N) for each course of interest. Engineering Communication was a class that was required for students starting Spring 2020 and was not available during pre-remote instruction

	Pre-Remote			**Remote**			**Post-Remote**		
Course	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Physics 1	949	2.63	0.83	336	2.98	0.7	531	2.56	1.04
Physics 2	614	2.73	0.80	244	2.97	0.78	307	2.75	0.79
Chemistry 1	652	2.48	0.99	246	2.48	0.92	363	2.24	1.18
Chemistry 2	440	2.36	0.84	205	2.49	0.85	287	2.24	1.02
Calculus 1	581	2.89	1.00	242	2.75	0.90	465	2.30	1.26
Calculus 2	604	2.59	1.10	211	3.02	0.74	323	2.57	1.18
Eng. Analysis	851	3.39	0.59	344	3.49	0.64	478	3.32	0.78
Eng. Computing	670	3.20	0.84	290	3.13	0.81	415	3.01	0.96
Comp. Seminar	442	3.51	0.72	361	3.54	0.56	511	3.40	0.83
Eng. Comm.				295	3.80	0.35	410	3.60	0.43

Table A2. Course grade anomalies before the COVID-19 Pandemic, during remote classes due to COVID-19, and after the return to in-person instruction. Mean and standard deviation (SD) of average grade anomalies, as well as number of students (N) for each course of interest. Engineering Communication was a class that was required for students starting Spring 2020 and was not available during pre-remote instruction

	Pre-Remote			**Remote**			**Post-Remote**		
Course	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Physics 1	949	–0.64	1.01	336	–0.20	0.64	531	–0.62	1.26
Physics 2	614	–0.48	0.60	244	–0.32	0.64	307	–0.48	0.55
Chemistry 1	652	–0.79	1.07	246	–0.75	0.74	363	–0.96	1.11
Chemistry 2	440	–0.73	0.57	205	–0.70	0.60	287	–0.83	0.67
Calculus 1	581	–0.26	1.44	242	–0.48	1.05	465	–0.86	1.78
Calculus 2	604	–0.55	1.00	211	–0.21	0.85	323	–0.55	0.99
Eng. Analysis	851	0.36	0.57	344	0.44	0.46	478	0.43	0.66
Eng. Computing	670	0.18	0.75	290	0.00	0.60	415	0.01	0.73
Comp. Seminar	442	0.43	0.77	361	0.48	0.57	511	0.49	0.88
Eng. Comm.				295	0.73	0.58	410	0.65	0.66

Table A3. Average grade anomalies (AGAs), grades, and between-gender effect sizes for each course of interest in the four semesters before the COVID-19 Pandemic. Cohen's *d* is positive if men had higher grades or AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

	Women					**Men**						
		AGA		**Grade**			**AGA**		**Grade**		**Cohen's *d***	
Course	**N**	**Mean**	**SD**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Mean**	**SD**	**AGA**	**Grade**
Physics 1	376	–0.84	0.94	2.49	0.77	573	–0.51	1.03	2.71	0.86	0.33***	0.27***
Physics 2	198	–0.67	0.55	2.59	0.74	416	–0.39	0.60	2.8	0.82	0.48***	0.27**
Chemistry 1	234	–0.83	1.17	2.50	1.00	418	–0.77	1.01	2.47	0.99	0.05	–0.03
Chemistry 2	148	–0.74	0.55	2.39	0.77	292	–0.73	0.59	2.34	0.87	0.02	–0.06
Calculus 1	216	–0.22	1.45	2.97	0.99	365	–0.28	1.43	2.85	1.00	–0.04	–0.12
Calculus 2	209	–0.55	1.06	2.61	1.16	395	–0.54	0.98	2.57	1.07	–0.01	–0.03
Eng. Analysis	320	0.36	0.53	3.43	0.57	531	0.36	0.6	3.37	0.6	0.01	0.10
Eng. Computing	231	0.10	0.79	3.15	0.92	439	0.22	0.73	3.23	0.8	0.15	0.10
Comp. Seminar	161	0.59	0.79	3.68	0.58	281	0.34	0.74	3.42	0.77	0.33**	0.36***

Table A4. Average grade anomalies (AGAs), grades, and between-gender effect sizes for each course of interest in the two semesters of remote instruction due to the COVID-19 Pandemic. Cohen's *d* is positive if men had higher grades or AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

	Women					**Men**						
		AGA		**Grade**			**AGA**		**Grade**		**Cohen's *d***	
Course	**N**	**Mean**	**SD**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Mean**	**SD**	**AGA**	**Grade**
Physics 1	127	–0.32	0.64	2.94	0.71	209	–0.12	0.63	3.00	0.7	0.32*	0.09
Physics 2	87	–0.28	0.54	3.04	0.73	157	–0.34	0.69	2.93	0.81	–0.09	–0.15
Chemistry 1	79	–0.74	0.74	2.53	0.91	167	–0.75	0.73	2.46	0.92	0.01	0.07
Chemistry 2	70	–0.6	0.52	2.63	0.8	135	–0.75	0.63	2.41	0.87	0.25	0.26
Calculus 1	94	–0.56	1.11	2.74	0.82	148	–0.43	1.02	2.76	0.95	0.12	0.01
Calculus 2	78	–0.31	0.51	2.96	0.68	133	–0.15	1.00	3.05	0.78	0.19	0.11
Eng. Analysis	132	0.42	0.48	3.53	0.65	212	0.45	0.45	3.47	0.64	0.08	–0.09
Eng. Computing	103	–0.06	0.57	3.1	0.78	187	0.03	0.62	3.15	0.82	0.15	0.06
Comp. Seminar	138	0.57	0.6	3.67	0.53	223	0.43	0.53	3.45	0.55	–0.25*	–0.39***
Eng. Comm.	104	0.75	0.54	3.83	0.3	191	0.73	0.6	3.78	0.37	–0.03	–0.17

Table A5. Average grade anomalies (AGAs), grades, and between-gender effect sizes for each course of interest in the two semesters of in-person instruction after remote classes due to COVID-19. Cohen's *d* is positive if men had higher grades or AGAs than women in a course. * = p < 0.05, ** = p < 0.01, and *** = p < 0.001

	Women					**Men**						
		AGA		**Grade**			**AGA**		**Grade**		**Cohen's *d***	
Course	**N**	**Mean**	**SD**	**Mean**	**SD**	**N**	**Mean**	**SD**	**Mean**	**SD**	**AGA**	**Grade**
Physics 1	180	–0.95	1.55	2.36	1.03	351	–0.45	1.05	2.66	1.03	0.40***	0.29**
Physics 2	88	–0.61	0.5	2.72	0.74	219	–0.42	0.56	2.76	0.81	0.35**	0.05
Chemistry 1	106	–1.11	1.41	2.23	1.25	257	–0.91	0.96	2.25	1.15	0.18	0.01
Chemistry 2	82	–0.81	0.62	2.27	0.94	205	–0.83	0.69	2.24	1.05	–0.04	–0.03
Calculus 1	155	–1.21	2.31	2.21	1.33	310	–0.68	1.42	2.35	1.22	0.30*	0.11
Calculus 2	92	–0.41	0.83	2.71	1.05	231	–0.61	1.05	2.51	1.22	–0.2	–0.17
Eng. Analysis	156	0.4	0.72	3.28	0.82	322	0.45	0.62	3.33	0.76	0.08	0.07
Eng. Computing	126	–0.14	0.74	2.89	0.98	289	0.08	0.71	3.06	0.94	0.29*	0.17
Comp. Seminar	164	0.62	0.81	3.48	0.81	347	0.43	0.9	3.36	0.83	–0.21*	–0.14
Eng. Comm.	126	0.67	0.63	3.62	0.43	284	0.64	0.67	3.59	0.43	–0.05	–0.08