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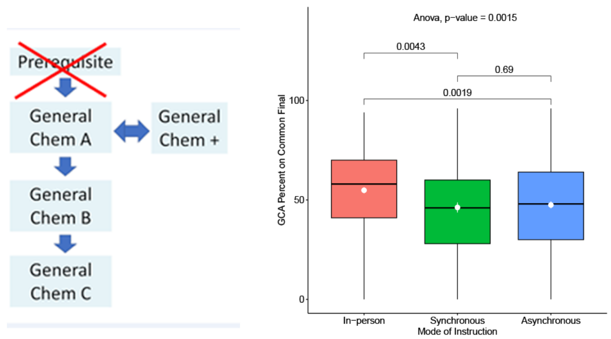
Abstract

An active-learning concurrent preparatory general chemistry course was adopted to replace a prerequisite course that lacked effectiveness in improving student outcomes. Our prior study showed that the concurrent course increased final exam performance and retention in a cohort of students. This paper studies the course modality impact of the concurrent preparatory course on student learning and retention. Three modes of instruction (in-person, online synchronous, and asynchronous) were offered for the concurrent preparatory general chemistry course. Significant differences were found in success on the final exam and retention for the first quarter of college-level general chemistry between in-person and online students. While students in the synchronous and asynchronous modalities performed differently in the concurrent preparatory general chemistry course, there were no significant differences in the final exam performance in the main general chemistry course or retention overall.

Keywords

First-Year Undergraduate / General, Curriculum, Testing / Assessment, Minorities in Chemistry, Collaborative / Cooperative Learning

Graphical Abstract



Introduction

Universities draw from a large and diverse pool of applicants who can benefit from a range of support systems.[1] For students entering college with a set of strengths that does not include specific required mathematical and scientific skills, these support systems have often taken the form of costly, time consuming, yet ineffective remedial courses. Though intended to help students, these courses have frequently been shown to be less effective than allowing students to enter college-level courses directly[2–9] and significantly hamper student time to degree.[4]

Participation in courses designed to academically support students in skill acquisition prior to the start of college-level courses is widespread across all demographics.[4] However, it is higher in low-income backgrounds, first-generation students, female students, and Black and Hispanic students.[4] It is, therefore, extremely important for equity in higher education that the effect of these interventions in these subgroups be considered.

A variety of programs have been trialed to provide additional academic support to students with varying degrees of success. One of the most popular choices involves students completing work before they start their first academic year by completing short "Bridge Programs". The success of these programs is varied, with some showing they help all students regardless of academic preparation.[10] However, these programs often aim to narrow opportunity gaps, which is especially important during the initial chemistry course.[11] Though bridge programs have been shown to improve outcomes for under-served populations, they do not close larger achievement gaps.[7] While giving students access to online homework resources in the summer prior to enrollment has been shown to improve learning outcomes, it largely does not reach the student population most in need of these resources.[8] Similar results are seen when requiring entire courses to be administered the summer prior to enrollment. California State University required enrollment in courses during the summer prior to admission, with no improvement when comparing fall enrollment or no prerequisite courses.[5] Though summer programs do ensure students can remain on track to finish their courses on time, they often come with a variety of financial costs and administrative difficulties that are not warranted, given the modest improvements in outcomes.

One model, which was shown to make gaps in success for under-served populations worse, involved creating a separate section of General Chemistry and providing extra support services. When comparing success in the course, though first-semester achievement gaps were narrowed, second-semester achievement gaps were increased[12] for those in traditionally underserved populations.

One explanation for the null to modest results for prerequisite courses is that the topics are too far removed from the college-level curriculum. Many skills correlated with student success, such as studying skills, prior subject knowledge, and critical thinking[13–17] can be taught concurrently with college-level coursework. One method of concurrent preparation involves supplemental instruction via increased instructional support, extended recitations, or peer mentoring. These have largely been shown to increase learning gains in under-served populations.[16,18–25] In addition to learning gains, peer-led sessions can increase the sense of belonging and emotional satisfaction in students historically underrepresented in STEM,[20] and should be considered to promote other skills such as collaboration and group study skills.[26] These data are compelling enough, that Texas[27] and Tennessee[28] have both instituted widespread regulation requiring corequisite options.

Active learning has been shown to reduce achievement gaps in underserved populations.[29,30] The effects of high-structure,[31] group-oriented,[32,33] problem based learning[34,35] is well established[36,37] and should be integrated into courses for increased equity. Research at our own university has shown these results apply to our student population.[38–40]

In our prior publication,[41] we discussed the implementation and design of a concurrent enrollment preparatory course in general chemistry. Offering a full concurrent enrollment course provided the benefits of supplemental instruction. Using a standardized general chemistry final as a metric, student success was analyzed and compared to that of their peers. Performance improvements on the common final exam, as well as improvements in the one-year retention, were observed.[41]

Deciding who should be placed into preparatory chemistry classes has various difficult aspects.[42,43] Though many placement testing methods have been developed,[44–46] they are costly and largely ineffective.[2,47] Students identified via placement tests as requiring additional preparation often perform just as well as those who are not identified as needing extra support.[3,48] The unnecessary courses taken by students due to these inaccurate placements lower the successful completion of college-level courses.[3,49,50] Using multiple methods of placing students can maximize the efficiency of placement.[51] Placement models that use high school performance metrics, compressed remediation, personalized remediation courses, and allowing the first exam in a college course to place students have attempted to reduce these placement test difficulties.[2,52,53]

Starting in Fall 2021, the University of California no longer requires SAT scores for application and admission. This resulted in a significantly larger enrollment in the concurrent enrollment preparatory course in general chemistry (GC+) than in previous years. To accommodate increasing enrollment in GC+, students could take the course asynchronously online, synchronously via zoom, or synchronously in a classroom.

It is also important to note that improving support for skill acquisition is only one small aspect of reducing opportunity gaps. We acknowledge that skill acquisition alone is not enough to overcome institutional barriers to success for under-served communities.[54–57] Other initiatives at the university, school, and department levels work to continually address other barriers to success for marginalized populations.[40,58–70]

The primary focus of this study is to understand the impact of course modality of GC+ on the general chemistry sequence (GCA, GCB, and GCC). We investigated the following:

- GC+ student characteristics across course modalities
- GC+ Student performance outcomes in the first quarter of General Chemistry (GCA).
- GC+ Student retention in the General Chemistry sequence

Course Logistics and Design

The course was initially set up as an in-person course in a room large enough to accommodate 400 students, with three fifty minute meetings on Monday, Wednesday, and Friday. An asynchronous option was added due to a scheduling conflict of a subset of biology students and a large number of students who needed this course. In addition, students had an option of attending the in-person section remotely via Zoom. This resulted in three modalities for taking GC+. To gain more information about the primary mode of their learning, all GC+ students (n = 468) were asked to fill out a required exit survey. The survey had a 99% response rate. GC+ students were asked, “What was the primary mode of learning you used in GC+? Select the one that best describes your approach in the majority of the situations".

- Mostly in-person (by coming to the classroom for lectures and quizzes)

- Mostly asynchronously (with most of your learning activities happening outside the assigned lecture time window)
- Mostly on Zoom (by connecting to real-time Zoom sessions for lectures and quizzes)

Table 1 presents the distribution of the mode of instruction that students chose for GC+. The majority of students took the course online; 40% synchronously via zoom and 18% asynchronously online. 42% of the students took the course in-person. The course logistics allowed for significant flexibility to accommodate various needs of the students, and also provided a natural experiment allowing for the examination of the effect of learning choices on performance and retention. GC+ students concurrently enrolled in GCA in the same term. Across the five sections of GCA, the GC+ students' representation ranged from 15-29%.

Table 1: Mode of Instruction for GC+

Mode	n	%
In-person	195	42
Synchronous online	83	18
Asynchronous online	187	40
Not disclosed	3	<1
	468	100

Regardless of the mode of instruction, the students had the same assignments and covered the same topics in this course (Table 2). Topics were synchronized to GCA course to the extent possible. Additionally, several prerequisite topics were covered which are not covered in GCA but are imperative to the next two-quarters of general chemistry (GCB and GCC). The first week was devoted to reviewing math fundamentals and use of units because they are essential to students' success in chemistry courses. Weeks 2-6 covered key GCA topics that students have an especially difficult time with, including the relationship between subatomic particles and the periodic table of elements, energy, wave properties of elementary particles, atomic configurations and period trends, empirical and molecular formulas, Lewis structures, polarity, and dipole moments. Prerequisite topics for GCB, GCC or GC Labs which are not always included in GCA and were therefore included in GC+ were: reaction stoichiometry, limiting reagents, naming of chemical compounds, and basics of solutions. Because students who take GC+ are especially vulnerable to falling behind, we devoted an entire lecture to metacognition in week 9. The course ended with a set of cumulative problems testing students on the entire set of topics in week 10.

Table 2: Covered Course Topics in Fall 2021

Week	Monday	Wednesday	Friday
1	Units, scientific notation, significant figures	Metric conversions, dimensional analysis	Quiz on week 1 topics
2	subatomic particles, isotopes, atomic numbers	Moles and molar conversions	Quiz on week 2 topics
3	Energy and intro to thermochemistry, bond energies	Wave nature of light and particles	Quiz on week 3 topics
4	Wavefunctions, quantum numbers, orbitals, energy level diagrams	Periodic trends	Quiz on week 4 topics
5	Types of bonds, molecular formulas, ionic formula units	Empirical formulas and weight percent	Quiz on week 5 topics
6	Lewis structures, formal charges, resonance	Electronegativity, bond polarity, dipole moments	Quiz on week 6 topics
7	Balancing reactions, reaction stoichiometry	Limiting and excess reagents, theoretical and actual yield	Quiz on week 7 topics
8	Naming covalent compounds, ionic compounds, anions, and acids	Solution concentrations and dilutions.	Quiz on week 8 topics
9	Metacognition and learning strategies	Holiday	Holiday
10	Review of all topics	Review of all topics	Quiz with problems that mix two concepts

The course followed the same pattern every week (Figure 1). Students were asked to watch a few short pre-recorded videos (10 min each) and submit short pre-lecture quizzes before the Monday and Wednesday lectures to make sure they come prepared. Each video covered one topic, and the quiz problems were relatively simple and directly correlated with the videos.

The Monday and Wednesday lectures split the time between material review by the instructor, polling questions, offered with help of PollEverywhere, and going over the polls to review common mistakes. Students taking the course in-person and on Zoom responded to PollEverywhere questions during the lectures. Students taking the course asynchronously or students who could not attend the lectures were asked to answer the same polling questions in survey format between the end of the Wednesday lecture and the start of next week's Monday lecture. Regardless of how the students responded to the polling questions, their responses were graded based solely on participation.

The students submitted homework assignments before Friday lecture, which were more comprehensive than the Monday and Wednesday pre-lecture quizzes. The Friday lecture periods were devoted to end-of-week quizzes. The quizzes opened at the start of the lecture and could be submitted in a 30 hour window following the lecture, in order to accommodate the students taking the course asynchronously. The pre-lecture assignments on Monday, Wednesday and Friday could be taken an unlimited number of times, and end-of-week quizzes had two attempts, with the highest score kept. All of the assignments could be submitted after the deadline but there was a late submission penalty of 10% per day. The penalty was removed for students who requested extensions due to sickness or other emergencies, and it was retroactively removed for everyone during week 10 of the quarter to encourage students to catch up on their work and become better prepared to their GCA final exam. A sample of each assignment type is included in the supplemental information.

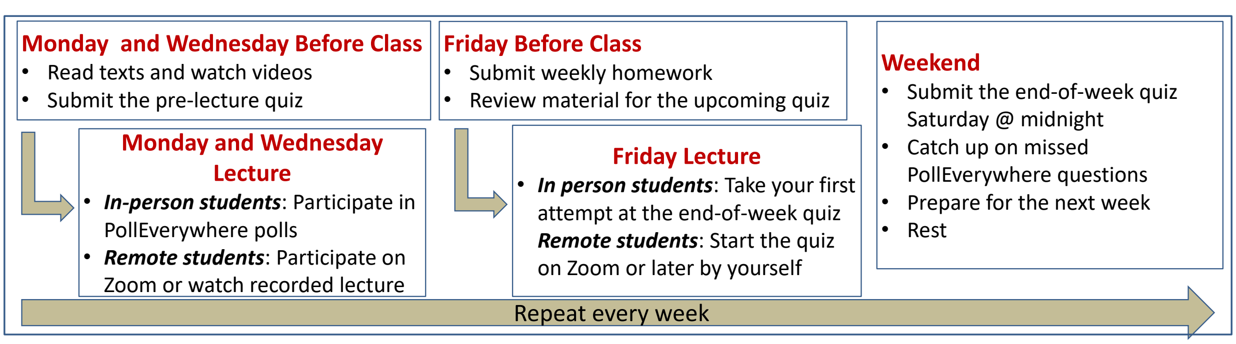


Figure 1: Weekly Structure in GC+

All of these assignments, apart for the PollEverywhere questions, were programmed in Canvas using either multiple-choice or "Formula" questions, a feature of Canvas, in which each student gets their own starting values and cannot simply copy the answer from others without understanding how to solve the problem. We adopted an open book, open-discussion format for all of the Friday quizzes, in which students could freely talk to each other. The lecture room was configured with swiveling seats to promote active discussions between students during the quizzes. According to the exit course evaluations, this open-book, open-discussion format and flexibility in timing greatly reduced the level of students' anxiety about learning and made the process more welcoming and engaging for them. We do not anticipate that any significant academic dishonesty occurred. The structural assessment policies lead to very little incentive to engage in academic dishonesty. Assessments were low-stakes, open-note, and students were allowed to work together in groups. Additionally, the class was graded P/NP, so a desire for a higher letter grade would not create a strong incentive for dishonest behavior.

To increase the availability of available assistance during active learning, the course employed 10 undergraduate learning assistants (LAs) and 4 graduate teaching assistants (TAs) actively helping in the class. This was necessary due to the high enrollment of the course along with the multiple modalities. One of the TAs and two LAs were assigned to Zoom rooms to help students taking the quizzes remotely.

GC+ was configured as a P/NP class. In order to pass, students had to gather 700 out of 1000 possible points (Table 3). A two-hour final exam was offered as an alternative way to pass the course for students who have taken most of the assignments but have not been able to gather 700 points. To be eligible for this alternative passing option, the students must have attempted 7 out of 9 end-of-week quizzes. A valid "attempt" was defined as a submitted quiz with a non-zero score. The final exam consisted of randomly pooled assignments from the set of end-of-week quizzes. The majority of the students (418 out of 472) were able to pass the course without having to take the final exam, leaving 36 students who got another chance to pass by taking the final exam and 18 students who did not pass and were not eligible to take the final because of the insufficient amount of work done during the quarter. Of the 36 students who were eligible to take the final, 20 were able to pass it, 8 attempted it but could not pass, and 8 elected not to take it. The final passing rate was 438 out of 472 students.

Table 3: Summary of course assignments

Category	Assignments	Points
End-of-Week Quizzes	Total 9 Canvas-based quizzes, 60 points each, graded based on accuracy	540
PollEverywhere	Several polls offered live every Monday and every Wednesday during lecture periods, graded based on participation, make up polls provided at the end of the week	145
Homework	Total 9 Canvas-based homework modules, 15 points each, graded based on accuracy	135
Pre-class (Video) Quizzes	Total 18 Canvas-based pre-class quizzes, 10 points each, graded based on accuracy	180
Total		1000

Common Final Structure and Data Collection

All students enrolled in GCA are required to take a standardized final exam. The 50-question multiple-choice exam is administered on Sunday of Week 11 during a three-hour block. Due to continuing pandemic-related concerns, the exam was administered online using the Canvas Learning Management System with Respondus Monitor as a proctoring system. A full list of questions are available in the supplemental instruction.

The exam is written collaboratively by the general chemistry instructors and is instructor-agnostic. The raw scores are available for comparison by asking the GCA course instructor for a CSV file of all students' common final scores and ID numbers. All professors agreed to share the raw common final scores. The common final was worth 40% of the grade in three sections and 30% in two sections of GCA. The common final scores were compared for GC+

students who took the final in each of the three learning modalities. This provides data for comparison, which is minimally impacted by instructors' course policies. Students' choice of modality in GC+ did not strongly depend on the choice of instructor in GCA and had a similar distribution ($\chi^2 = 10.74$, $p = 0.217$).

Student Selection and Participation

The study occurred during a ten week quarter in Fall of 2021. IRB approval was granted via UCI IRB (UCI IRB:2637). The study population consisted of all students enrolled in GC+. The chemistry department allows several admittance paths to GCA (Table 4). Students who enrolled in GCA without enrolling in GC+ were not evaluated in this study. Some students who took the online ALEKS adaptive homework (one of the possible ways of fulfilling GCA prerequisites) still chose to take GC+; these students were included in the study given their enrollment in GC+. Descriptive information of the students included in the study can be found in the Demographic section.

Table 4: Pathways for Entrance to General Chemistry A (GCA)

	Description
1	SAT Math Reasoning test score of 600 or higher
2	ACT Math test score of 27 or higher
3	AP Chemistry exam score of 3
4	SAT Chemistry subject exam score of 700 or higher
5	Completion of or concurrent enrollment in Calculus or Classical Physics
6	Adaptive online homework instruction modules using ALEKS
7	Concurrent enrollment in GCA and GC+

Statistical Analysis

Data analyses were carried out using the open-source programming environment R[71] and with the *ggplot2* packages.[72] Data visualizations include box plots providing the minimum, 25th percentile, median, 75th percentile and the maximum[73] (see supplemental materials for further discussion). To test for the difference in average academic performance for the three modes of instruction, we conducted an analysis of variance (ANOVA) using an overall F-test.[74,75] The ANOVA tables are included in the supplemental materials and include the degrees of freedom (Df), sum of squared errors (Sum Sq), mean squared errors (Mean Sq), F test statistic (F value), and the respective p-value for the overall F-test. To test if there is a difference across the three modes of instruction, we conducted all possible pairwise comparisons (between modes of instruction) using Tukey's honestly significant difference (HSD) procedure.[76–78] The Tukey HSD procedure allows us to conduct multiple comparisons of means while keeping the family-wise error rate low (i.e., the overall Type I error rate is kept low).

Comparing Student Similarities and Differences Across Modes of Instruction

Reasons for Modality Choice

GC+ students reported their reason(s) for choosing the in-person and online course, respectively (Table 5). The driving factor for choosing the in-person mode of instruction was based on their learning preference for in-person instruction. Students who chose the online mode of instruction primarily did so due to their school scheduling conflicts (66%-70%). Many online students also preferred the online mode of instruction (49%-58%). Online students were more likely to select that mode of instruction (35%-41%) due to personal circumstances compared to in-person students (21%). While a higher percentage of online students chose that mode for health concerns around the COVID-19 pandemic (10%-20%) compared to in-person students (5%), the overall health concerns were on the whole relatively small. It was interesting that some in-person students wanted to have that mode of instruction for their health concerns, presumably for increased mental wellness.

Table 5: Self-Reported Reasons for Selecting Mode of Instruction for GC+.

		Online		
	In-person	Synchronous	Asynchronous	Total
Reason	%	%	%	%
Learning preference for particular mode of instruction				
Yes	84	58	49	65
No	16	42	51	35
Total	100	100	100	100
School scheduling conflicts limiting your choices				
Yes	38	66	70	56
No	62	34	30	44
Total	100	100	100	100
Personal circumstances such as caring for family, work, long commuting limiting your choices				
Yes	21	35	41	31
No	79	65	59	69
Total	100	100	100	100
Other considerations				
Yes	19	7	5	12
No	81	93	95	88
Total	100	100	100	100
Lack of access to or comfort/ability with technology limiting your choices				
Yes	16	7	5	10
No	84	93	95	90
Total	100	100	100	100
Health concerns around the COVID-19 pandemic limiting your choices				
Yes	5	20	10	10
No	95	80	90	90
Total	100	100	100	100

Demographics

Table 6 provides the student characteristics across the different instructional types. The main reason for providing the demographic breakdown across modalities is to understand who is choosing to take the corequisite course in-person compared to online. While GC+ students are primarily female, first-generation status, low-income, and PEERs (persons excluded due to ethnicity or race), there does not appear to be significant differences in modality choice based on those characteristics. The percentage of low-income students and PEERs is similar across the different modes of instruction. But for synchronous online sections of GC+, there is a higher percentage of first-generation students (69%) compared to in-person and asynchronous online sections (63%-64%).

A variety of majors are enrolled in GC+, with students from Biological Sciences being the highest representation (regardless of the mode of instruction). Physical Sciences students have greater representation in the online sections (16%-17%) compared to the in-person section (11%). Most of the GC+ students have few external units, i.e., advanced placement credit and transfer credits, with only a small percent of GC+ students coming in with 4+ external units. We also note that the high school GPA for the in-person students was slightly higher compared to the online students.

Demographics in courses designed to serve traditionally excluded populations typically are over-represented in females, PEERs, low-income, and first-generation college students. In this study, we found that the GC+ students concurrently taking GCA in Fall 2021 were similar in terms of sex and number of external units. However, there were higher proportions of first-generation students, low income students, and PEERS. The high school GPA of the GC+ students were slightly lower than those of the GCA general population.

Table 6: Student characteristics. The first three columns represents the different modalities of GC+ students. The fourth column provides the overall percents for all GC+ students. The last column provides the student characteristics for students in GCA in Fall 2021 who did not take GC+.

	GC+ Modality				GCA
	In-person	Online			General
		Synchronous	Asynchronous	GC+	Population
Variable	%	%	%	%	%
Sex					
Female	74	70	72	72	67
Male	26	30	28	28	33
First-Generation					
Yes	63	69	64	65	39
No	37	31	36	35	61
Low Income					
Yes	57	59	57	58	36
No	43	41	43	42	64
PEERs					
Yes	75	73	74	74	43
No	25	27	26	26	57
Major					
Biological Sciences	41	41	44	42	55
Physical Sciences	11	17	16	14	5
Undecided/Undeclared	19	13	7	13	10
Public Health	10	11	12	11	8
Engineering	6	13	9	8	12
Humanities	8	2	10	7	0
Social Science, Nursing	5	3	2	5	10
External Units					
0-3 units	94	98	97	96	96
4-7 units	3	1	2	2	2
8-11 units	3	1	1	2	2
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
High School GPA	3.94 (0.24)	3.84 (0.51)	3.86 (0.40)	3.89 (0.37)	4.00 (0.52)

Performance Outcomes

Across the three modes of instruction for GC+ (in-person, synchronous, and asynchronous), there was a difference in academic performance in GC+ ($p < 0.001$). Table 7 presents the summary statistics. The p-value of the overall F-test is shown at the top of Figure 2 (for the full ANOVA table, please refer to the supplemental materials). When looking at the pairwise comparisons for GC+ performance, in-person students performed differently than synchronous students ($p = 0.003$, $p_{adj} = 0.031$), in-person students performed differently than asynchronous students ($p < 0.001$, $p_{adj} < 0.001$), and synchronous students performed differently than asynchronous students ($p = 0.003$, $p_{adj} = 0.007$). After using the Tukey HSD procedure and adjusting the p-values to account for multiple comparisons, we find that the results of the difference in academic performance in GC+ for each of the pairwise comparisons are still significant (Table 8). In terms of GC+ academic performance, in-person students performed significantly better than both synchronous and asynchronous students (Figure 2).

Table 7: Summary statistics of performance in GC+ and GCA across different modes of instruction.

GC+ Mode of Instruction	GC+ Percent in Class Mean (SD)	GCA Percent on Common Final Mean (SD)
In-person	83 (13)	55 (21)
Synchronous	77 (17)	46 (22)
Asynchronous	69 (24)	47 (23)

Table 8: Tukey HSD pairwise comparisons of performance in GC+ across the modes of instruction.

		95% Confidence Interval		
Comparison Groups	Difference	Lower Bound	Upper Bound	p-value
Synchronous-(In-person)	-6.15	-11.85	-0.45	0.031*
Asynchronous-(In-person)	-13.62	-18.07	-9.17	<0.001*
Asynchronous-Synchronous	-7.48	-13.21	-1.74	0.007*

The p-values in this table are adjusted for multiple comparisons.

Figure 3 presents the performance on the GCA common final for the three groups of

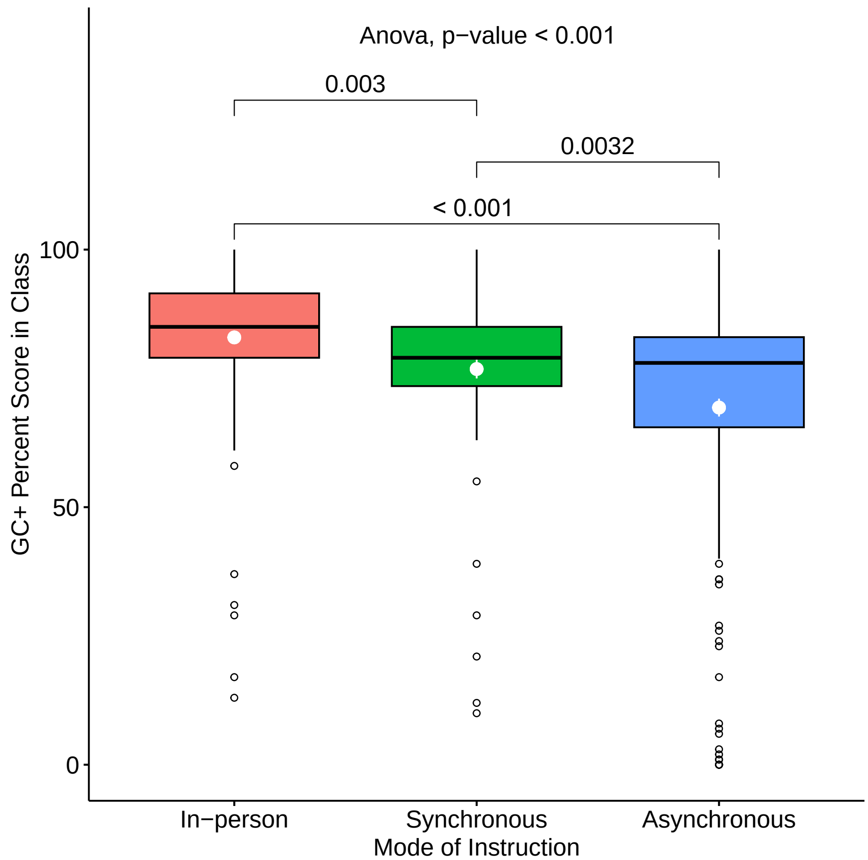


Figure 2: Performance in GC+ (percent score in class). The p-value for the overall F-test for the difference in means of the GC+ percent score in class across the three modes of instruction are presented at the top of the plot. The (unadjusted) p-values for the pairwise comparisons of the GC+ percent score in class are presented on top of each horizontal bar. See supporting information for assistance in reading box plots if needed

GC+ students, with the p-value for the overall F-test shown at the top of the figure. Across the three modes of instruction for GC+, there was a difference in academic performance of the GC+ students on the common final for the concurrent GCA course ($p = 0.002$). Table 7 presents the summary statistics for academic performance on the common final in the concurrent GCA course across the 3 modes of instruction in the GC+ course (see the supplemental materials for the corresponding ANOVA table). When looking at the pairwise comparisons for the GC+ students' GCA performance, in-person GC+ students performed differently than synchronous GC+ students on the GCA common final ($p = 0.004$, $p_{adj} = 0.01$) and in-person GC+ students performed differently than asynchronous GC+ students on the GCA common final ($p = 0.002$, $p_{adj} = 0.01$). However, for the synchronous GC+ students and asynchronous GC+ students there was no difference in performance on the GCA common final ($p = 0.69$, $p_{adj} = 0.91$). After using the Tukey HSD procedure and adjusting the p-values to account for multiple comparisons, we find that the results of the difference in the GC+ students' academic performance on the common final for the concurrent GCA course for each of the pairwise comparisons are still consistent in terms of significance (Table 9).

Table 9: Tukey HSD pairwise comparisons of performance in GCA (percent on common final exam) for GC+ students based on different modes of instruction.

		95% Confidence Interval		
Comparison Groups	Difference	Lower Bound	Upper Bound	p-value
Synchronous-(In-person)	-8.63	-15.61	-1.64	0.01*
Asynchronous-(In-person)	-7.38	-12.93	-1.82	0.01*
Asynchronous-Synchronous	1.25	-5.84	8.34	0.91

The p-values in this table are adjusted for multiple comparisons.

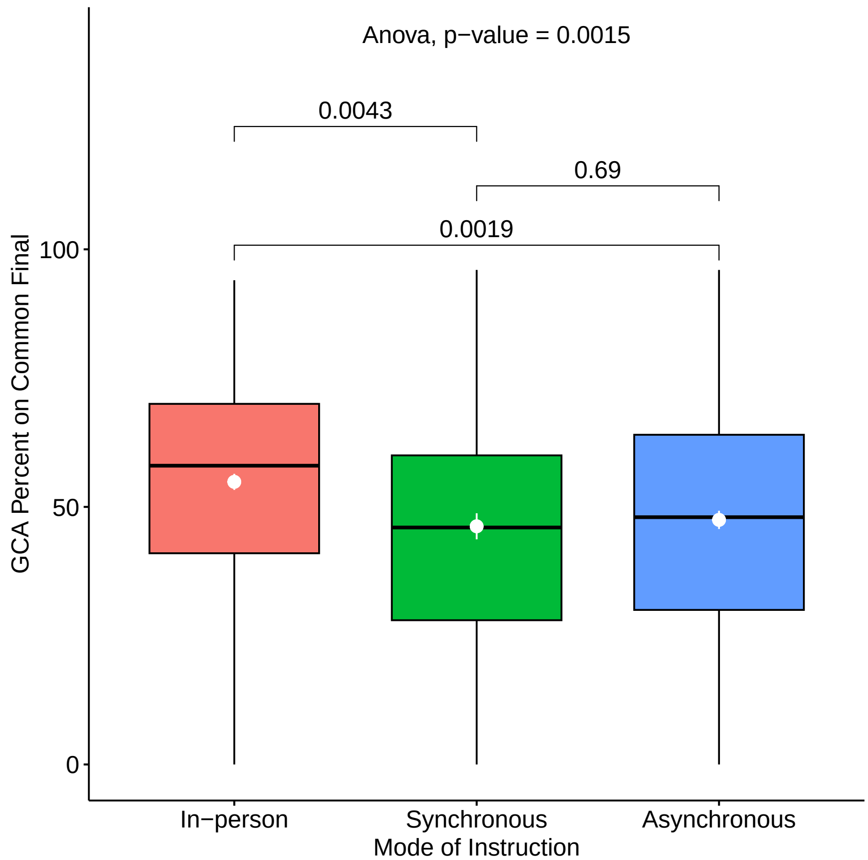


Figure 3: Performance in GCA (percent on common final) for GC+ students. The p-value for the overall F-test for the difference in means of the GCA percent on common final across the three modes of instruction are presented at the top of the plot. The (unadjusted) p-values for the pairwise comparisons of the GCA percent on common final are presented on top of each horizontal bar. The mean and respective standard errors for each group are given in white. See supplemental information for assistance in reading box plots if needed.

Grade Outcomes

We observed a difference in grades in GCA across the three modes of instruction for GC+ students ($p < 0.001$). Students who attended GC+ in-person achieved higher grades in GCA by approximately half a GPA point; summary statistics are presented in Table 10 and the respective overall F-test across the different modes of instruction for the grades in general chemistry are presented in the supporting information. In GCB and GCC, which were taken by students after the completion of GC+, there was not a significant difference in grades achieved regardless of which modality GC+ was taken (GCB: $p = 0.854$, GCC: $p = 0.711$). Table 11 presents the results of the Tukey HSD pairwise differences in grades in general chemistry across the different modes of instruction. For GCA, there was a significant difference between the in-person and online students. Students who took GC+ in-person also received higher grades in the concurrent GCA course compared to both the synchronous students ($p = 0.011$, $p_{adj} = 0.02$) and asynchronous students ($p < 0.001$, $p_{adj} < 0.001$). Similar grades in GCA were achieved regardless of whether the students took the GC+ course synchronously or asynchronously ($p = 0.67$, $p_{adj} = 0.90$). This is consistent with what is seen on the common final exam scores (Figure 3). Box plots of the GC+ students performance in GCA, GCB, and GCC can be found in the supplemental files.

Table 10: Summary statistics of grades in general chemistry based on GC+ mode of instruction.

GC+ Mode of Instruction	GCA Grade Mean (SD)	GCB Grade Mean (SD)	GCC Grade Mean (SD)
In-person	2.02 (1.22)	1.88 (1.08)	1.83 (1.08)
Synchronous	1.57 (1.30)	1.82 (1.21)	1.67 (1.41)
Asynchronous	1.49 (1.24)	1.93 (1.11)	1.84 (1.05)
All Students	**1.73 (1.27)**	**1.89 (1.11)**	**1.81 (1.13)**

Table 11: Tukey HSD pairwise comparisons of performance in general chemistry (grade in course) for GC+ students based on different modes of instruction.

Course	Comparison Groups	Difference	95% Confidence Interval Lower Bound	Upper Bound	p-value
GCA	Synchronous-(In-person)	-0.45	-0.86	-0.05	0.02*
	Asynchronous-(In-person)	-0.53	-0.84	-0.21	<0.001*
	Asynchronous-Synchronous	-0.07	-0.48	0.33	0.90
GCB	Synchronous-(In-person)	-0.06	-0.49	0.38	0.95
	Asynchronous-(In-person)	0.05	-0.30	0.40	0.94
	Asynchronous-Synchronous	0.11	-0.35	0.56	0.84
GCC	Synchronous-(In-person)	-0.17	-0.68	0.35	0.72
	Asynchronous-(In-person)	0.01	-0.39	0.40	>0.99
	Asynchronous-Synchronous	0.17	-0.37	0.71	0.73

The p-values in this table are adjusted for multiple comparisons.

Retention

Students who attended GC+ in person maintained higher enrollment and pass rates than their online peers throughout the General Chemistry sequence. Figure 4 provides the enrollment rates across the general chemistry sequence for GC+ students across different modalities (please refer to the supplemental materials for the corresponding table that accompanies the figure). Nearly all GC+ students were concurrently enrolled in GCA regardless of in-person, synchronous, or asynchronous choice. Less than 10% of students were taking GC+ without being simultaneously enrolled in GCA. An enrollment drop in GCB was seen for all groups. However, enrollments were highest for in-person, followed by synchronous, and lastly, asynchronous. Another drop was seen across all groups for enrollment in GCC. While students who attended GC+ in-person still saw the highest enrollment rates, there were similar rates for synchronous and asynchronous students. Pass rates followed the same pattern. Throughout the entire general chemistry sequence (GCA, GCB, GCC), GC+ students who chose the in-person modality had the highest pass rates. And for students choosing the online modalities for GC+, pass rates are similar throughout the general chemistry sequence regardless of the student attending GC+ synchronously or asynchronously.

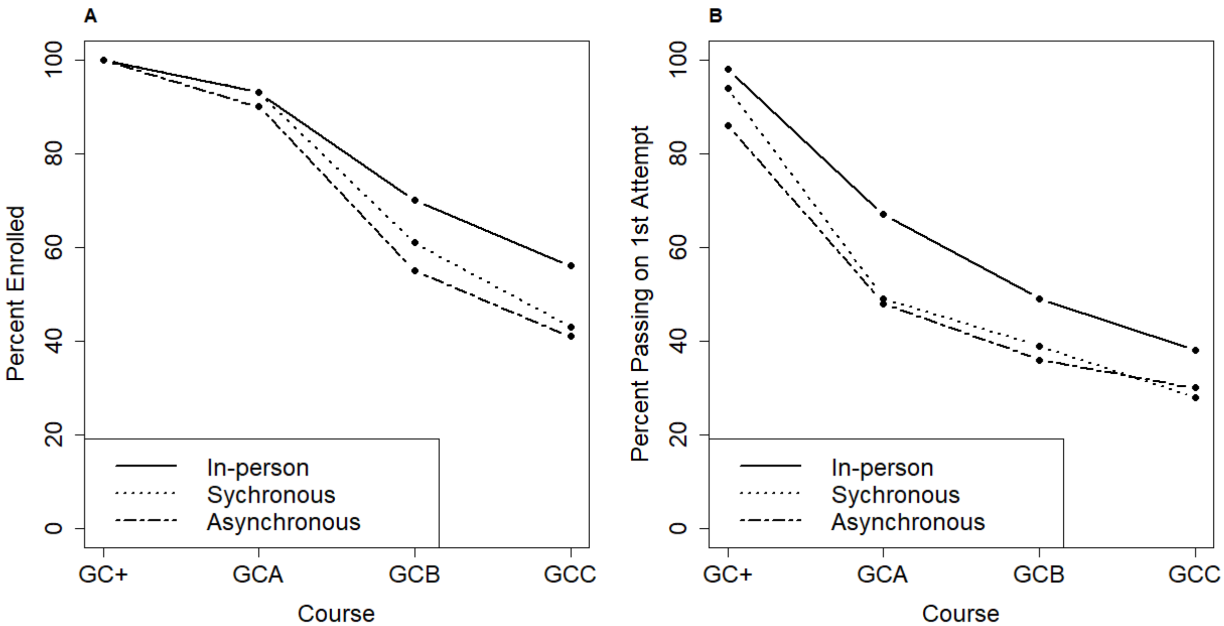


Figure 4: Enrollment and retention of GC+ students throught the general chemistry sequence. Figure A displays the percent enrolled in each course. Figure B shows the percent of students passing on the first attempt conditional on enrollment in the course.

Discussion

In this study, we investigated the relationship between GC+ course modality with common final exam performance and retention. We found that a much higher percentage of students who attended the in-person GC+ class went on to take GCB and GCC. And a higher percentage initially took their first GCB and GCC on sequence (Supplemental Table 1). This continues to support the importance of in-person options for preparatory courses, and it extends our understanding of corequisite courses. While our previous study[41] showed positive effects of the concurrent enrollment preparatory course on common final exam performance, this study suggests that course modality may moderate the impact. And while students performed best in general chemistry if they attended GC+ in person, further research in improving the online course offerings is needed. Additionally, further research on how to improve alternate course modalities structure to improve performance would be of significant interest.

Among online students, those taking the course synchronously were more likely to enroll in GCB than their asynchronous peers. However, pass rates in GCB for the synchronous and asynchronous students were relatively similar. For online students, GCC enrollment and pass rates are similar regardless of synchronous attendance. Similar to the data on common final exam performance, these data suggest little benefit in requiring synchronous attendance if an online course is necessary. Though performance for the online students was lower, no significant difference was seen between asynchronous and synchronous modalities. This calls into question policies for online courses which enforce synchronous attendance. It also supports the use of in-person classrooms for preparatory classes while working to improve online course offerings.

Additionally, we investigated how modality impacted course grades and pass rates. These have significantly more confounding variables due to different professors teaching GCA, GCB, and GCC. When comparing students who took GC+ on their grades in GCA, it is observed that in-person attendance correlates to the best performance. This was true when comparing both GCA pass rates and grades. When looking only at pass rates, no notable difference was seen in GCA performance between the asynchronous and synchronous modalities. However, there was a difference in grades in the online students, with synchronous students doing better than asynchronous ones. Because course grades are subject to many instructor-specific policies, it is impossible to know definitively why this difference was seen between grades and final exam outcomes. However, due to overall scores in GC+ showing similar patterns as that in GCA grades, it may indicate that performance on homework and in-class participation were contributing factors. Future studies need to collect instructor-specific data to investigate this phenomenon further.

Limitations

While some students had to use asynchronous modality due to a scheduling conflict and had no other choice, many other students self-selected into the course modality. Therefore, minor selection effects of the modality are being measured, as well as the impact of the modality. The selection effects were minimized due to significant scheduling conflicts (56% of students reported scheduling conflicts), but they cannot be removed entirely. Additionally, scheduling conflicts could introduce a bias towards students depending on their degree path. While this is a limitation of the study, it is also a significant limitation that our universities face. If universities offer multiple modalities of preparatory classes, there will naturally be self-selection into the courses. This can potentially widen opportunity gaps, and the selection effects should be considered in developing course-offering options. However, if universities do not provide a variety of options for course modality, they risk excluding students who would otherwise not be able to take the course. Identifying systemic barriers for students and increasing opportunities to engage in STEM is requires a multi-faceted approach to the nuances of providing options in course modalities. Furthermore, the determination of modality was completed by students' self-report. This is subject to self-report errors and may not accurately reflect students who are evenly split over multiple modalities.

While the focus of this paper is not on the differential impacts of course modality on subgroups of students, we recognize that certain groups have not self-selected completely at random. While the percentage of low-income students and PEERs is similar across the different modes of instruction, there is a higher percentage of first-generation students in the synchronous online class compared to in-person and asynchronous online sections. These groups have been traditionally marginalized and under-served in the STEM community. GC+ offers a unique chance for these student populations to have additional support, access to instructors, and access to graduate students to address inequities in support given to them previously. It is also worth noting that due to the removal of the SAT scores as a selection metric, effects such as student confidence levels could impact whether they chose to enroll in GC+ rather than using self-taught methods to meet the prerequisite. Due to sociocultural impacts on this population, they may be more likely to enroll. Because we are using institutionally collected data we have demographic data on gender as opposed to gender identity. This limits our discussion of gender. It was encouraging to see that there were not obvious patterns of choice of modality across available demographic characteristics and thus variations in common final exam performance and retention are unlikely due to variations in demographic characteristics.

The common final is the best metric for learning outcomes that is currently available to us. It is also the largest single contributing factor to the grade and the most direct measure of learning outcome achievement because it is not directly affected by instructor course policy. However, this metric does have limitations. In three sections, it was worth 40% of the grade, in two sections, it was worth 30% of the grade. The final exam was meant to be instructor-agnostic, however no assessment is completely detached from the instructional policies and pedagogical practices.There was a similar distribution across the five sections, ranging from 15-29%. Future studies should seek to fully validate the final exam as a metric for learning outcomes and seek to determine the impact of course and instructor policies on performance. Further studies would be required to ensure the common final is adequately measuring learning outcomes.

Due to consistently high enrollments (n = 1946, Fall 2019), our implementation required significant LA and TA support even though only approximately 24% of students took GC+. For universities with significantly smaller enrollment, it is possible that LA and TA support would not be needed. The focus on active learning, engaging with the material, time on task and additional instructor support were the main focuses of our implementation.

Conclusion and Implication

The benefit of a corequisite preparatory course on common final exam performance and retention was associated with the choice of course modality of the preparatory course. Students who chose to take the course in-person did significantly better than those who attended online. However, little difference was seen when comparing whether students attend synchronously online via Zoom or asynchronously via Zoom recordings. Also, the benefits associated with the corequisite course tapered off in terms of performance as the general chemistry sequence progressed. This suggests that the timing of the course curriculum should be considered when developing both preparatory courses and general chemistry courses.

We suggest that Chemistry departments should continually monitor the success of different course modalities and consider an iterative approach to improving courses. Departments should consider how to provide access to students while monitoring (and making appropriate adjustments) to the course design and structure to mitigate possible negative impacts. As the student population continues to change and as departments strive to achieve both equity and excellence, attention to both preparatory and introductory courses is imperative. Departments should investigate the impacts of putting preparatory courses online as well as strive to understand who is afforded opportunities by more flexible course offerings.

Additionally, in our institutional context, it does not seem that forcing online synchronous content delivery for students helps increase exam performance or retention. This is important because synchronous requirements may cause disparate difficulties across populations. Our data support that how students ingest online content is not a major source of concern in terms of retention. Further study to determine how to optimize the impact of corequisite preparatory courses is still needed.

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Supporting Information Available

The following files are available free of charge.

- Box Plot Example and Description
- Performance Outcomes: ANOVA tables of performance in GC+ and GCA across modes of instruction.
- Grade Outcomes: ANOVA tables and box plots of grades in GCA, GCB, and GCC across modes of instruction.
- Retention: Table of Success of GC+ Students in General Chemistry. Table including percent of GC+ students enrolled in GCA, GCB and GCC. Including the pass or DFW rates within each course.
- Common Final Exam Questions
- Sample Weekly Homework Assignment
- Sample PollEverywhere questions

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