Improving Students' Performance and Decreasing the Academic Equity Gaps in Gateway Chemistry Course by Course Redesign in Favor of Evidence Based Teaching Approaches and Increased Course Structure

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Abstract

Academic equity gaps in groups of underrepresented students are one of the most concerning problems in higher education, especially in gateway courses where students learn the foundational skills and knowledge to succeed in upper division courses. The effect of the course redesign in favor of a blended high structure course delivery format on student performance in gateway General Chemistry course was evaluated using a logistic regression analysis and qualitative summative content analysis. Four versions of General Chemistry course taught by the same instructor were assessed based on the course final grades. The sample design included students enrolled in the traditional face-to-face low structure course, control section 1 (spring 2018), with initial population 89; a blended predominantly online low structure course, control section 2 (spring 2021), with initial population 93; two blended high-structure courses, experiment in current research: 80% online 20% face-to-face (spring 2022), and 50% online 50% face-to-face (spring 2023), with initial populations 86 and 88 students respectfully. Findings suggest that blended high structure course design with the flipped classroom teaching/learning model offered in conjunction with Supplemental Instruction significantly enhanced student performance.. It was found that a blended high structure course delivery format when offered in 50% online 50% face-to-face proportion has a better effect on student academic performance and led to a meaningful decrease in C-DFW grade percentage by 9.69% and 21.64% as compared with control sections 1 and 2, respectfully. This blended delivery structurealso led to elimination of the academic equity gaps within several groups of students including students of color and first-generation students.

Keywords: course redesign, flipped classroom, gateway course, high structure course, supplemental instruction

1. Introduction

Currently, a course redesign of high-enrollment, low division courses, or gateway courses, in favor of evidence-based teaching practices is one of the successful ways in transformation of higher education in Science, Technology, Engineering and Mathematics (STEM) field. In gateway courses students learn the foundational skills and knowledge to succeed in upper division courses. Unfortunately, the rate of student success in gateway courses is low. This slows down students' progress, leading to poor pass rates, and retention rates. Poor performance, especially in gateway courses, is a major reason why STEM-interested students from all backgrounds switch to non-STEM majors or drop out of college altogether (Chen, 2013; Dika & D'Amico, 2016). Underrepresented college students, first-generation college students, or low-income students tend to have the lowest rate of success, causing the largest academic equity gaps relative to their overrepresented peers in gateway STEM courses, as reflected through examination scores and failure rates. (Alexander et al., 2009; Haak et al., 2011).

Academic equity gaps in groups of underrepresented students are one of the most urgent and persistent problems in higher education. According to recent statistics, Black/African American and Hispanic/Latino individuals comprised 14.2% and 21.3% of the U.S. population aged 20-34 but were awarded only 8.7% and 16.3% of STEM bachelor's degrees in 2019 and comprised only 5.1% and 7.6% of STEM workforce respectively (National Science Board, National Science Foundation, 2022). Broadening participation in the science requires instructors to reduce the barriers underrepresented minorities face in the undergraduate courses (Gibbs & Marsteller, 2016).

Existing inequity in gateway courses has several major reasons. The large enrollments and significant amounts of content the gateway courses cover make it difficult for instructors to meaningfully engage students. The diverse student population creates another obstacle especially for students in minority or underrepresented groups that have different backgrounds, expectations, and experiences.

Recently, blended courses with a meaningful proportion of face-to-face and online support are gaining popularity as alternatives to traditional face-to-face classes due to their pedagogical flexibility in course delivery, opportunity to incorporate active learning more effectively, efficient usage of classroom space and stuffing needs through reduction in the in-person class time while still allowing meaningful student-instructor interaction.

Our research examines the course redesign and effects of the simultaneously implemented evidence-based teaching approaches – the flipped classroom teaching/learning model in conjunction with the two forms of Supplemental Instruction (SI) on improvement of the student learning outcomes and decreasing the academic equity gaps in a blended gateway General Chemistry I course. Such increased course format has a lack of literature reports.

However, in the past 10 years, studies on the effectiveness of the flipped classroom teaching model have become abundant in chemistry education research. It was shown that flipped classroom teaching/learning approach positively impacts student learning outcomes compared to traditional lecture-based instructor-centered model. The definition of a flipped classroom is almost universally defined as a class structure in which some portion of traditional in-person didactic lecture is transferred to independent pre-class learning mode, with traditional lecture being replaced by active learning exercises. The exact nature of the pre-class and in-class learning activities varies widely among the studies reported in literature (Eichler, 2022). In contrast to a traditional lecture-based, instructor-centered instructional model, the flipped classroom model is composed of two phases of instruction that are “flipped,” “inverted” or “reversed” (Bergmann & Sams, 2012).

The first phase of the flipped classroom model is the pre-class learning phase. In this phase students gain knowledge by viewing instructor provided learning materials in various media formats, such as online videos, podcasts, or text-format materials prior to class (Baker & Wesley, 2000). The pre-class learning phase with well-designed activities can reduce the cognitive load for students and meaningfully contribute to learning. Moving some of the traditional lecture content into a pre-class phase provides an opportunity to incorporate active learning strategies during face-to-face in-class meetings.

The second phase of the flipped classroom model is the in-class learning phase. In this phase students have student-centered active learning activities, such as interactive lectures, problem solving, laboratory experiments, role playing, and collaborative design and creation (Gerstein, 2011). Thus, in terms of Bloom’s revised taxonomy (2001) students are doing the lower levels of cognitive work (acquiring knowledge and understanding) outside of class and concentrating on the higher forms of cognitive work (analysis, application, synthesis, and assessment) in class (Bergmann & Sams, 2012).

Recent meta-analyses of the educational research literature provide evidence that the flipped classroom can be considered an evidence-based instruction practice (EBIP) that leads to both improved student performance outcomes and higher student satisfaction relative to traditional teaching. The results also suggest that the flipped classroom has the potential to close the academic equity gap in gateway chemistry course outcomes (Rahman & Lewis, 2020; Bredow et al., 2021).

However, it is not clear what aspects of the flipped classroom contribute most to the observed improvement in student learning outcomes with such diverse activities that are implemented during the pre-class and in-class phases of the flipped classroom and what factors contribute most to the increased student achievement. Chemistry educators are encouraged to focus on optimization of the flipped classroom with the ongoing challenge to promote skill-based learning, deeper conceptual understanding of Chemistry and ways of thinking (Eichler, 2022).

We consider that optimization of the flipped classroom teaching/learning model can be achieved through combination of the active learning that the flipped model offers with Supplemental Instruction and high impact tutoring. It is known that the courses with high structure that require pre-class preparation, intensive active learning activities and regular exam practice are more effective in reducing the achievement gaps for low-income and underrepresented students because they increase deliberate practice and sense of community (Haak et al., 2011).

Educational researchers have developed evidence-based practices designed for Supplemental Instructions and high impact tutoring. In Supplemental Instruction, peer "SI Leaders" facilitate learning in sessions outside of regular class hours for high-risk courses, mostly the gateway STEM courses. SI Leaders are students who have previously been successful in the course, have good communication and leadership skills and are motivated to help other students to succeed. SI Leaders do not provide additional instruction to the students but create active lessons that foster interactive cognitive input from the group of attending students. The students attending the sessions participate in constructing their knowledge, while the SI Leader serves as a guide along the way. SI has significant evidence that it is an effective method for improving student learning outcomes in gateway STEM courses and benefit underrepresented and low performed students by narrowing the achievement and affect gaps (Hensen & Shelley, 2003; Stanich et al., 2018).

Recognizing the benefits of a Supplemental Instruction model and understanding how difficult chemistry courses can be, we modified a traditional SI model in fall 2019 and implemented a faculty-facilitated learning enhancement tutoring model to help students in addition to normal lectures. With this modification, 1.5 of weekly office hours were converted by Dr. Stackpool to separate optional tutoring/help sessions conducted by the author to enhance and support classroom discussions. The students were organized into learning teams. Each team included 3-5 students. The team worked together to complete the assignment which involves a set of 7-10 problems relating to lectures offered during the previous week. All team members participated and contributed equally since only one set of answers/solutions can be submitted from a team. Each student succeeds when all team members succeed, and each member of the team receives a bonus point added to their examination score on the next upcoming exam.

The benefits of the suggested model are numerous. Students gain knowledge through interaction and conversations articulating their understanding. The informal atmosphere supports students' ability to socialize and study together. Success becomes achievable for all team members, and it impacts the students' motivation and desire to learn. In fall 2020 and spring 2021 the tutoring sessions were conducted via Zoom due to the COVID-19 pandemic (Stackpool et al., 2023).

Gateway courses General Chemistry I and General Chemistry II at MSU, Mankato intend to lay the foundation for later work in higher level courses and they are required for all degrees in chemistry or biochemistry and several other majors in biological sciences and other non-science majors. Unfortunately for many students, these courses (especially General Chemistry I) have higher than average failure and withdrawal rates: 35%-50% of the students enrolled in these courses receive grades of C-, D, F or withdrawal, W. The underrepresented groups of students, students of color, first-generation college students, or lower-income students have the lowest rate of success. During the three recent academic years (2018/19, 2019/20 and 2020/21), the rate of receiving a grade of D, F, or W among students of color (SOC) exceeded that of white students by 11.0%. Class size of 72-96 students is also an obstacle to making these courses engaging for student participation. This strongly suggests that course redesign should be considered.

We hypothesize that course redesign in favor of a high structure blended course with the pre-class preparation, in-class active learning activities, supported by post-class Supplemental Instruction offered in two forms: peer-facilitated academic support system (MavPASS) and faculty-facilitated learning enhancement tutoring model in combination with traditional review sessions before exams, will improve students' performance in General Chemistry course including the performance of underrepresented groups of students through increase student interaction with learning material while reducing the in-class contact time.

The research objectives in this study address three key questions:

1. What impact does the course redesign in favor of a blended high structure teaching model have on student performance in gateway General Chemistry course based on pass/fail rate?
2. To what extent does the proportion of online vs. face-to-face activities in the blended course design effect the student learning outcomes?
3. Will the course redesign and implementation of the flipped classroom teaching/learning model in conjunction with the two forms of supplemental instruction promote a decrease in the academic equity gaps in a diverse student population of a gateway General Chemistry course?

The data analysis includes:

- A logistic regression analysis of data to determine if there is significant relationship between the blended high structure course model with different proportion of online vs. face-to-face activities in course delivery and the C-, D, F, W rate in the gateway General Chemistry course.
- A qualitative summative content analysis to analyze data obtained from student surveys.

Our current research is an ongoing project started in the spring semester of 2022. Approval of the current research project from the IRB was received in November 2021. The flipped classroom teaching model was implemented in General Chemistry I in conjunction with the supplemental instruction (faculty-facilitated learning enhancement tutoring) in spring of 2022. The data about the course grade in General Chemistry I for two spring semesters 2021(before implementation of flipped classroom teaching/learning - control) and 2022 (after implementation of the flipped classroom – experiment) were collected, compared, and analyzed.

Our results based on the data analyses revealed that the flipped classroom teaching/learning model provides an opportunity to learn in a differentiated and more equitable fashion which leads to a decrease in the academic equity gaps within several groups of students and significantly enhances student academic performance. The passing rate in General Chemistry I increased from 40.86% to 56.98% and the rate of failure decreased from 59.14% to 43.02% in 2022 vs. 2021. A decrease in the rate of withdrawal from 34.41% to 20.93% in 2022 was found to be a primary contributor to the failure rate decline in 2022. An increase in the rate of A-, B, C+ and C grades in 2022 resulted in a significant increase in the passing rate in 2022 (Stackpool et al., 2023). It was also found that the students exposed to the “flipped” learning in spring 2022 showed higher passing rate in the subsequent gateway course General Chemistry II with flipped classroom teaching/learning model. Among the students who were involved in the “flipped” learning for two semesters – spring 2022 (General Chemistry I) and fall 2022 (General Chemistry II) - the passing rate was higher (83.33%) compared to their counterparts who had one semester experience of the flipped classroom teaching/learning model in fall 2022 (71.80%). These two groups outperformed their counterparts who took General Chemistry II in fall of 2021 when the traditional lecture-based course delivery format was offered (61.19%). This finding is consistent with observations made by He, Holton and Farkas that a partially flipped undergraduate general chemistry course generally improved student performance in the subsequent course in the sequence, with a more pronounced effect for students with weaker incoming academic preparation (He et al., 2018).

2. Methodology and Methods

This project is based on the research methodology known as Participatory Action Research (PAR). Within an educational institution, this is research conducted *with* students, rather than *on* students. The outcomes of this collaborative research highlight the benefits to the instructors and students when they are involved in a research project using PAR methodology (Jacobs, 2016).

2.1 Design

Four versions of General Chemistry I course designed, implemented and taught by the author, Dr. Stackpool in spring semesters 2018, 2021, 2022, 2023 made up the course sample. The sample design included students enrolled in the traditional face-to-face low structure course, control section 1 (spring 2018), with initial population 89; a blended predominantly online low structure course, control section 2 (spring 2021), with initial population 93; two blended high-structure courses, experiment in current research: 80% online 20% face-to-face (spring 2022), and 50% online 50% face-to-face (spring 2023) with initial populations of 86 and 88 students respectfully. In our research by blended learning we accept all types of education that include some aspects of face-to-face learning and online learning (Hrastinski, 2019). Our results reported in this work include a comparison of the blended high structure courses with traditional face-to-face and blended predominantly online courses in terms of student final course grades. The four versions of General Chemistry course had different amounts of contact time, with the least in online and the most contact time in face-to-face course model. The number of assignments also varied in the four course versions. The blended high structure 2022 and 2023 versions had a large number of graded low-stakes assignments per week besides four hour exams. The Supplemental Instruction provided by instructor via Zoom was implemented first in 2021, was also offered in 2022 and was enhanced by another form of SI, peer-facilitated academic support system (MavPASS) in 2023. Overall, the difference between the four course versions is in increased course structure. A high-structure course is a course with multiple activities that are intended to promote better preparedness for class and motivation to attend class, improve student engagement with the course content through increased preparation time, and extensive student in-class engagement. Such activities include:

1. Preparation assignments in pre-class phase.
2. Engagement in active-learning during the in-class phase with frequent low-stakes practice assignments.

It was shown that these activities of high structure courses positively impact student performance (Eddy & Hogan, 2014; Freeman et al., 2014). Our model of the blended high-structure course also includes continuing engagement of students in active-learning in after-class time through optional Supplemental Instruction: 1) weekly tutoring sessions, 2) review sessions before exams and 3) peer-facilitated academic support system. The General Chemistry I course delivery methodology for four semesters is summarized in Table 1 below.

Table 1: Comparison of the course delivery methodology in spring semesters 2018, 2021, 2022 and 2023

Course delivery components	Low structure format		High structure format	
	Spring 2018 Traditional Face-to-face	Spring 2021 Blended mostly online	Spring 2022 Blended 80% online	Spring 2023 Blended 50% online
Face-to-face lectures 4 times a week	Yes	No	No	No
Online asynchronous lecture component	No	Yes	Yes	Yes
Mandatory study sessions 3 times a week	No	No	Zoom*	Face-to-face
(SI) Optional weekly tutoring sessions (10 per semester)	No	Zoom	Zoom	Zoom
(SI) Optional Peer-facilitated academic support system (MavPASS) (3 times a week)	No	No	No	Face-to-face
(SI) Optional review sessions before hour exams (4 per semester)	Face-to-face	Zoom	Zoom	Zoom
The hour and final exams	Face-to-face	Face-to-face	Face-to-face	Face-to-face
Laboratories	Face-to-face	Face-to-face	Face-to-face	Face-to-face
Online homework	Yes	Yes	Yes	Yes

Source: Stackpool, Premarathna, Leahy

*In spring 2022, due to the COVID-19 pandemic, Dr. Stackpool converted the originally planned face-to-face mandatory study sessions to remote sessions offered through live teaching platform, Zoom.

Online asynchronous lectures are pre-recorded videos posted on Desire to Learn (D2L) website. The videos have two formats: 1) explanations of concepts using PowerPoint presentations and 2) videos with examples of solving problems. Students can watch the videos based on their schedules and as many times as they want to grasp the concepts.

The mandatory study sessions help enhance students' knowledge of the concepts learned in the course and provide time to practice and build solid skills in problem-solving and answering conceptual questions. The worksheets for low-stakes assignments of each session included several problems. Each student's performance was graded, and each member of the team received up to 2 class participation points per session for a total of 84 points for 42 study sessions. Student teams were randomly selected. Active participation and attendance were required. The attendance varied from 70% to 86% (much better than that of regular lectures). Along with the online asynchronous lectures, the mandatory study sessions constitute the core components of the flipped classroom teaching/learning model, so called pre-class and in-class phases of this course delivery model.

The optional weekly tutoring sessions provide additional help, enhance and support lectures, study sessions, and lab-related content. The students were encouraged to take part in tutoring sessions. The tutoring session worksheets were graded each time and each student received a bonus point added to the examination score of the next upcoming exam.

In optional peer-facilitated academic support system (MavPASS), the "MavPASS Leaders", (the highly performing students) facilitate learning sessions outside of regular class hours.

The optional 50 minute review sessions before each hour exam are offered on the examination day.

2.2 Implementation of the Flipped Classroom Teaching/Learning Model

In spring semesters of 2022 & 2023 the flipped classroom teaching/learning model was implemented in General Chemistry I. All 86 (spring 2022) and 88 (spring 2023) General Chemistry I students enrolled in Dr. Stackpool's class were cordially requested to participate in this research project and to sign the Informed Consent Form available through Qualtrics.

By participating in the research, the students have agreed to the learning strategy below:

1. Study concepts of General Chemistry I course using prerecorded video lectures, online lecture notes, and the textbook.
2. Participate in the mandatory study sessions three times a week via Zoom (spring 2022) and face-to-face (spring 2023). The worksheets for each study session were available on D2L website in the submodule *Study Session*, 30-60 minutes before the study session started.
3. Participate in two anonymous surveys available through Qualtrics. The first survey was offered at the beginning of the semester. The second survey was conducted at the end of the semester.

Student surveys are the most reliable assessment of an instructor's effectiveness and are highly predictive of student achievement growth.

2.3 Data Collection/Participant Demographics

In our research we compared the student learning outcomes in terms of their final course grades before and after implementation of the flipped classroom model for low structure course format (spring 2018, spring 2021) vs. high structure course format (spring 2022, spring 2023). The data about final course grade for four semesters of General Chemistry I course were collected, compared and analyzed. The course grades for General Chemistry I students were requested from the Office of Institutional Analytics and Strategic Effectiveness for the following groups of students:

1. College Generation (First generation of a college student or non-first generation)
2. Gender Identity (Female, male, non-binary, choose not to disclose, other)
3. Student's major
4. The household income of the student (Low-income students, non-low-income students)
5. Ethnicity:

a) Student of color (Hispanic /Latino/ Spanish origin; African American; Asian American; Native American or Alaska Native; Native Hawaiian/other Pacific islanders).
b) Caucasian (White)

The participants' demographics is presented in Table 2. The data does not include names or tech IDs but it is linked to each other.

Table 2: Students' demographics in General Chemistry I in spring semesters

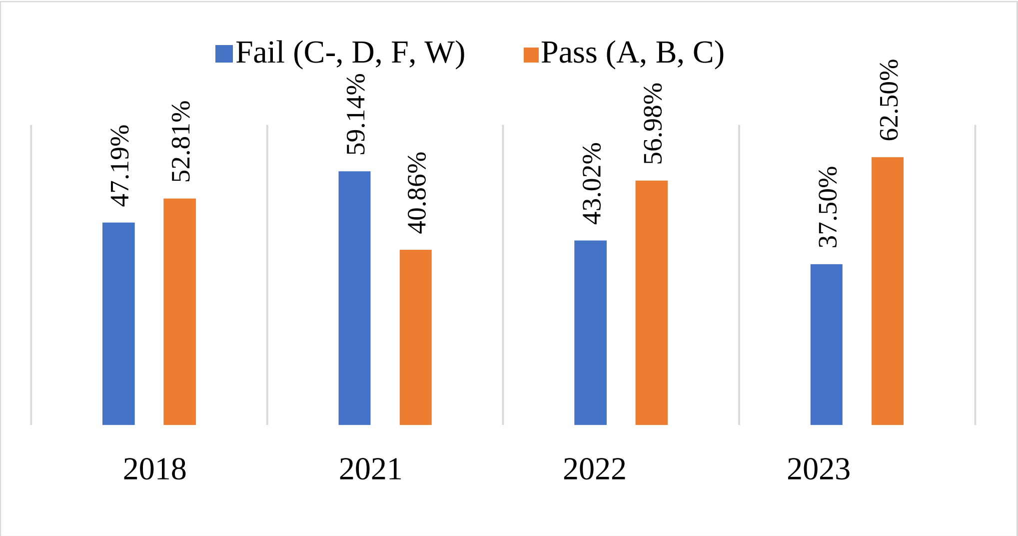
Groups of students		2018	2021	2022	2023
Gender:	Male	42.70%	35.48%	48.84%	39.77%
	Female	57.30%	64.52%	50.00%	59.09%
	Unknown gender	--	--	1.16%	1.14%
Ethnicity:	White students - Caucasian students	77.53%	82.80%	80.23%	77.27%
	Students of color (SOC)	22.47%	17.20%	19.77%	22.73%
Generation:	First-Generation students	44.94%	36.56%	38.37%	29.55%
	Non-First-Generation students	55.06%	63.44%	59.30%	68.18%
	Unknown	--	--	2.33%	2.27%
Total family income:	Low-income students, < $41,625	29.21%	12.90%	13.95%	14.77%
	Non-low-income students, > $41,625	70.79%	87.10%	86.05%	85.23%
Major: All majors were categorized into six categories	*Biology* – Biology, Biotechnology, Environmental Science, Agricultural Science, Food Science Technology, Life Science Teaching, Medical Lab Science	57.30%	55.91%	55.81%	57.95%
	Exercise HLTH – Exercise Science, Applied Health Science	7.87%	10.75%	20.93%	12.50%
	Chemistry – Chemistry, Biochemistry, Chemistry Teaching	4.49%	8.60%	6.98%	4.55%
	Civil-Eng.-Construction – Civil Engineering and Construction management	12.36%	3.23%	2.33%	--
	Earth Science	--	4.30%	--	--
	Other major – Major not specified, Geography, Elementary Education, Psychology, Family Consumer Science, Management, Cognitive Science, Computer Engineering Technology, Criminal Justice, Physics Teaching, Computer Science, Finance, Computer Information Technology, Music	17.98%	17.20%	13.95%	25.00%

Source: Stackpool, Premarathna, Leahy

3. Results and Data Analyses

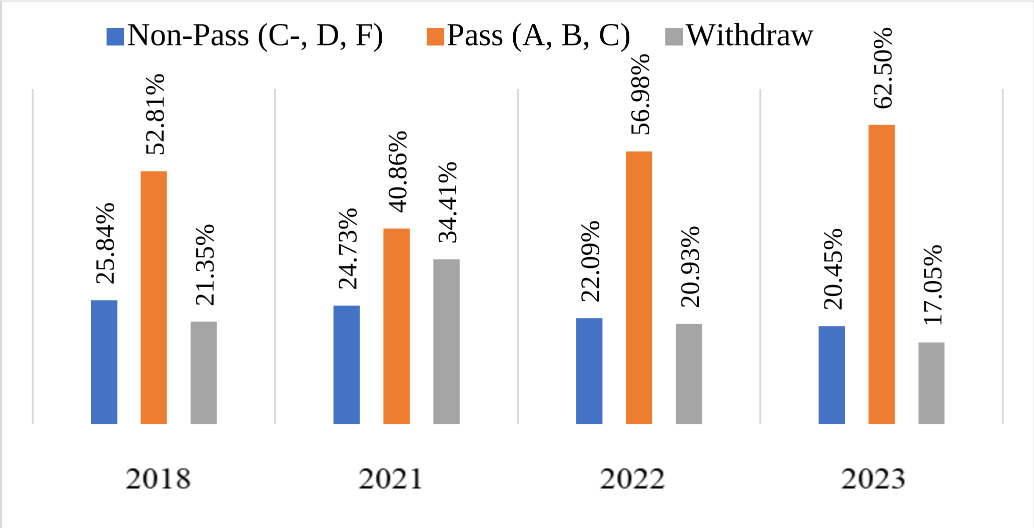
Figure 1 reveals a significant increase in the students' passing rate from 52.81% to 62.50% and a decrease in the rate of failure from 47.19% to 37.50% during five year period from 2018 to 2023. A significantly lower passing rate 40.86% and much higher fail rate 59.14% were observed in 2021 during the lock-down period caused by the COVID-19 pandemic when the students experienced such issues as isolation, low motivation and low engagement. A blended high structure course delivery format in 2023 when offered in 50% online 50% face-to-face proportion has better effect on student academic performance and led to a more noticible decrease in the rate of failure: C-DFW grade percentage decreased by 9.69% and 21.64% as compared with control sections 1 (2018) and control section 2 (2021) respectfully. Transition of the mandatory study sessions from online to face-to-face format and implementation of another form of SI, (MavPASS) led to further decrease in C-DFW percentage from 43.02% in spring 2022 to 37.50% in spring 2023. Figure 2 reveals a decrease in the rate of non-passing grades from 25.84% to 20.45% and a decrease in the rate of withdrawal from 21.35% to 17.05%. These results reflect the decline in the failure rate during the same five year period.

Figure 1: General Chemistry I Fail/Pass Distribution, % in 2018, 2021, 2022, 2023



Source: Stackpool, Premarathna, Leahy

Figure 2: General Chemistry I Non-Pass/Pass/Withdraw Distribution, % in 2018, 2021, 2022, 2023



Source: Stackpool, Premarathna, Leahy

3.1 Logistics Regression Modeling

The following are the variables that we focused on for our analysis.

Term:

- Spring 2021 – (Before the flipped classroom teaching model was implemented)
- Spring 2022 – (After the flipped classroom teaching model was implemented)
- Term_LH: Teaching Format
    - L – Low structure format (Data from Spring 2018 and Spring 2021)
    - H – High structure format (Data from Spring 2022 and Spring 2023)

GradePF: Pass Fail Grade

- P: (Pass grade for A, A-, B+, B, B-, C+, C)
- F: (Fail grade for C-, D+, D, D-, F, NC, W)

In our previous study (Stackpool et al., 2023), we observed the presence of an association between grade and the teaching models of Spring 2021 and Spring 2022. We also found that the passing rate in Spring 2021 was significantly less than that in Spring 2022 with the flipped classroom teaching model. The logistic regression model also supported our finding by showing the chance of obtaining a passing grade with the flipped classroom model (2022) is about 1.9 times that of a regular classroom model (2021).

In the current study, we used a similar method to study the effectiveness and impact of course redesign in favor of blended high-structure teaching format compared to a traditional low-structure teaching format on the student learning outcomes based on their course passing grades.

When comparing grades between high and low-structure teaching formats, the hypothesis test reveals that grades are significantly associated with the teaching format with a p-value of 0.0135 (Table 3).

Table 3: Statistics for Table of GradePF by Term_LH

Statistic	DF	Value	Prob
Chi-Square	1	6.0986	0.0135
Likelihood Ratio Chi-Square	1	6.1180	0.0134
Continuity Adj. Chi-Square	1	5.5852	0.0181
Mantel-Haenszel Chi-Square	1	6.0815	0.0137
Phi Coefficient		-0.1309	
Contingency Coefficient		0.1298	
Cramer's V		-0.1309	

Source: Stackpool, Premarathna, Leahy

Since there seems to be a significant association between grades and the teaching format, we tested the hypothesis by comparing the passing rates of high-structure vs. low-structure teaching formats.

Ho: Passing rate with high-structure teaching format = Passing rate with low-structure teaching format

Ha: Passing rate with high-structure teaching format > Passing rate with low-structure teaching format

The p-value of 0.009056 when testing the above hypothesis suggests that the passing rate with a high-structure teaching format is significantly higher than the passing rate with a low-structure teaching format.

Then we used logistic regression to confirm our findings to show the importance of the method of teaching in student learning outcomes. The SAS software for modeling purposes was used.

Table 4: Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept		1	-0.1321	0.1486	0.7901	0.3741
Term_LH	H	1	0.5280	0.2144	6.0627	0.0138

Source: Stackpool, Premarathna, Leahy

According to the above SAS outputs of the analysis, a p-value of 0.0138 (Table 4) explains that the teaching format is significant in determining the student learning outcomes. This also explains that the high-structure teaching format versus a low-structure teaching format increases the log odds of passing grades by 0.5280 (Table 4). In other words, the chance of obtaining a passing grade with a high-structure teaching format is about 1.695 times that with a low-structure teaching format (Table 5).

Table 5: Odds Ratio Estimates

Effect	Point Estimate	95% Wald Confidence Limits	
Term_LH H vs L	1.695	1.114	2.581

Source: Stackpool, Premarathna, Leahy

3.2 Evaluation of Academic Equity Gaps

Evaluation of academic equity gaps among diverse student groups with the complex backgrounds and circumstances they bring to college is an important step in providing students the necessary support to succeed. The evaluation of academic equity gaps was performed using the percentage point gap method (PPG method) (Klonoski et al., 2017). The percent of students who passed the course and received grades of A, B, C for the entire population and the percent of students who achieved this criterion for target groups were calculated first. Next, the percent of students who passed the course within the entire population is subtracted from the percent of students achieving the criterion in the target group according to formula: *PPG = Group's passing rate,% – Passing rate for all students,%*

Table 6 summarizes data about the PPG values for the groups of students in our study.

Table 6: Percentage Point Gaps for Groups in General Chemistry I course in 2018, 2021, 2022, 2023

	SOC	First Generation	Low Income	Male	Female	Biology	Chemistry	Exercise Science	Other Major
2018: Passing rate is 52.81% for all groups									
Groups' passing	55.00	32.50	46.15	44.74	58.82	49.02	75.00	71.43	37.50

rates, % A, B, C									
PPG: Group, % - 52.8 %	2.19	-20.30	-6.66	-8.07	6.01	-3.79	22.19	18.62	-15.31
2021: Passing rate is 40.86% for all groups									
Groups' passing rates, % A, B, C	43.75	32.35	25.00	36.36	43.33	50.00	75.00	40.00	13.04
PPG: Group,% - 40.86%	2.89	-8.51	-15.86	-4.50	2.47	9.14	34.14	-0.86	-27.82
2022: Passing rate is 56.98% for all groups									
Groups' passing rates, % A, B, C	52.94	51.52	41.67	50.00	65.12	54.17	66.67	72.22	40.00
PPG: Group,% - 56.98%	-4.04	-5.46	-15.31	-6.98	8.14	-2.81	9.69	15.24	-16.98
2023: Passing rate is 62.50% for all groups									
Groups' passing rates, % A, B, C	65.00	69.23	46.15	68.57	57.69	58.82	50.00	63.64	72.73
PPG: Group,% - 62.50%	2.50	6.73	-16.35	6.07	-4.81	-3.68	-12.50	1.14	10.23

Source: Stackpool, Premarathna, Leahy

The PPG method compares the student learning outcomes of a disaggregated group and the reference group (entire population). For the groups where the PPG is a positive number, no academic equity gap exists and this group is not experiencing disproportionate impact. A negative PPG indicates the group is performing below the level of the entire population, and this group might be experiencing a disproportionate impact and academic equity gap. The magnitude of percentage point gap values to indicate disproportionate impact is not defined precisely. Usually, PPG of 3 percent may indicate disproportionate impact when there is a 30 points range between the highest and lowest group scores. Since this range is found in the data collected in table 6, we may conclude that the First Generation, Low Income, Male students, Biology and Other Major groups experienced disproportionate impact and academic equity gaps in 2018. Similar conclusion would be appropriate for the First Generation, Low Income, Male students and Other Major groups in 2021. Students of color (SOC), First Generation, Low Income, Male and Other Major groups were disproportionately impacted in 2022. Only three groups experienced this impact in 2023: Low Income, Male and Biology major. The PPG for Chemistry major group (n = 4) in 2023 was also found to be negative, -12.50% (Table 6). With so small group size, there is no conclusive evidence of the disproportionate impact and academic equity gap in this group in 2023.

The percentage point gap minus one method (PPG-1 method) was also used in our study to increase the sensitivity of the PPG method (California Code of Regulations, 2022). This method removes the influence of the group's own performance on the overall comparison rate and improves the accuracy by accounting for the number of students included in a group. According to the PPG-1 method the passing rate of all *other* groups, % is subtracted from the passing rate of the targeted group. The percentage point gap minus one (PPG-1) was calculated according to formula:

PPG-1 = Group's passing rate,% – Passing rate for all other students, %.

The detection of disproportionate impact in the PPG-1 method uses a threshold or margin of error (E) that is adjusted by the group size and passing rate of the group. The margin of error was calculated based on a 95% confidence level. E of 3% is found if the sample size (group size) is at least 800 ($n \geq 800$). The margin of error decreases as the sample size increases. In calculations of margin of error for a 95% confidence interval we used the following formula:

$$E = 1.96\sqrt{\frac{p \cdot (1-p)}{n}}$$

where p is group's passing rate, n is group's size, $1.96 = Z_{\alpha/2.}$

If PPG-1 was found within the limits of the margin of error: -E% < PPG-1 < E% or greater than or equal to the threshold: PPG-1 ≥ E%, then no adverse disproportionate impact and no academic equity gap is being detected. Disproportionate impact happens and the equity gap exists when the PPG-1 ≤ -E%. The comparison of results of the observed PPG-1 values to the margin of errors, E based on the groups' sizes and the their passing rates are summarized in table 7 for the groups of students with the observed negative PPG values reported in table 6.

Table 7: Passing Rates, PPG-1 and Margin of Error (E) for selected groups in 2018, 2021, 2022, 2023

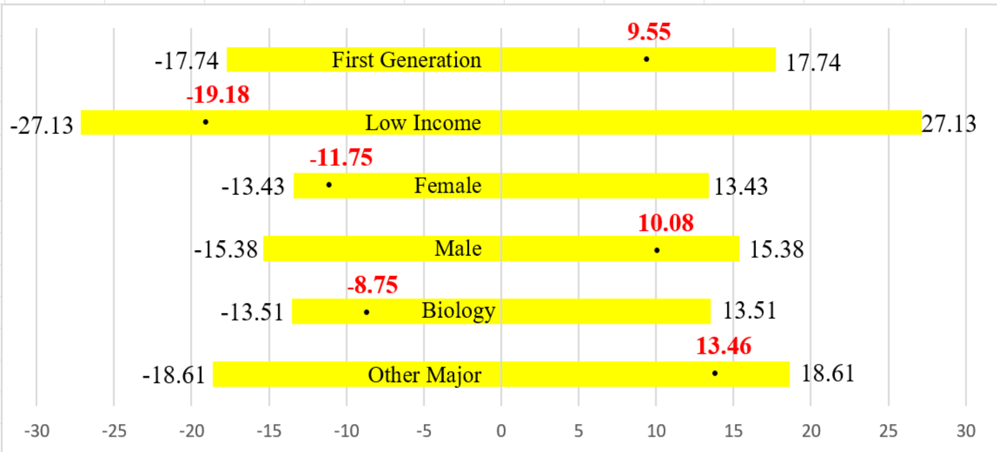
Groups	Years	Group's size	Group's passing rate	Passing rate of all other groups	PPG-1	Threshold (E)	Comparison of E and PPG-1
1st Generation	2018	40	32.50%	69.39%	- 36.89%	14.52%	-36.89% < - 14.52%
	2021	34	32.35%	45.76%	-13.41%	15.72%	-15.72% < -13.41% < 15.72%
	2022	33	51.52%	60.34%	- 8.82%	17.05%	-17.05% < -8.82% < 17.05%
	2023	26	69.23%	59.68%	9.55%	17.74%	- 17.74% < 9.55% < 17.74%
Low Income	2018	26	46.15%	55.56%	- 9.41%	19.16%	- 19.16% < -9.41% < 19.16%
	2021	12	25.00%	43.21%	- 18.21%	24.50%	-24.50% < -18.21% < 24.50%
	2022	12	41.67%	59.46%	- 17.79%	27.90%	-27.90% < - 17.79% < 27.90%
	2023	13	46.85%	65.33%	-19.18%	27.13%	-27.13% < -19.18% < 27.13%
Male	2018	38	44.74%	58.82%	-14.08%	15.81%	-15.81% <-14.08% < 15.81%
	2021	33	36.36%	71.67%	-35.31%	16.41%	-35.31% < -16.41%
	2022	42	50.00%	63.64%	-13.64%	15.12%	-15.12% <-13.64% < 15.12%
	2023	35	68.57%	58.49%	10.08%	15.38%	-15.38% <10.08% < 15.38%
Female	2018	51	58.82%	44.74%	14.08%	13.51%	14.08% > 13.51%
	2021	60	43.33%	36.36%	6.97%	12.54%	-12.54% < 6.97% < 12.54%
	2022	43	65.12%	48.84%	16.28%	14.24%	16.28% > 14.24%

	2023	52	57.69%	69.44%	-11.75%	13.43%	- 13.43% < -11.75% < 13.43%
Biology	2018	51	49.02%	57.89%	- 8.87%	13.72%	- 13.72% < -8.87% < 13.72%
	2021	52	50.00%	29.27%	20.73%	13.59%	20.73% > 13.59%
	2022	48	54.17%	60.53%	- 7.36%	14.10%	-14.10% < - 7.36% < 14.10%
	2023	51	58.82%	67.57%	- 8.75%	13.51%	- 13.51% < - 8.75% < 13.51%
Other Major	2018	16	37.50%	56.16%	- 18.66%	23.72%	-23.72% < - 18.66% < 23.72%
	2021	16	13.04%	46.75%	- 33.71%	16.50%	-33.71% < - 16.50%
	2022	12	40.00%	59.46%	-19. 46%	27.72%	-27.72% < - 19.46% < 27.72%
	2023	22	72.73%	59.09%	13. 46%	18.61%	- 18.61% < 13.46% < 18.61%

Source: Stackpool, Premarathna, Leahy

For very small group size (n ≤ 10), it is not advisable to estimate the disproportionate impact using this method. Therefore, the Chemistry major group was excluded from the analysis. In addition, the margin of error, E will be too wide (greater than 30%) when n ≤ 10. Table 7 reveals that the most of the PPG-1 values are negative which indicates that a group's course passing rate is lower than the all *other* groups passing rate. However, only for the First Generation group in 2018, Male group in 2021 and for the Other Major group in 2021, PPG-1 values were found large enough to consider disproportionate impact since the PPG-1 < -E%. Three of four positive PPG-1 values, for Female group in 2018, 2022 and Biology major in 2021 exhibit positive disproportionate impact or disproportionate advantage since PPG-1 ≥ E%, suggesting that these groups of students were performing better compared to all other students. The other PPG-1 values are found inside the threshold of the margin of error, -E% < PPG-1 < E%. In these cases there is no conclusive evidence of disproportionate impact or academic equity gaps being experienced by these groups of students. This last case is illustrated below in figure 3 which visualizes the location of the PPG-1 in comparison to the margin of error, E for the groups listed in table 7 in 2023.

Figure 3: PPG-1 values and Margine of Errors for Selected Groups in 2023

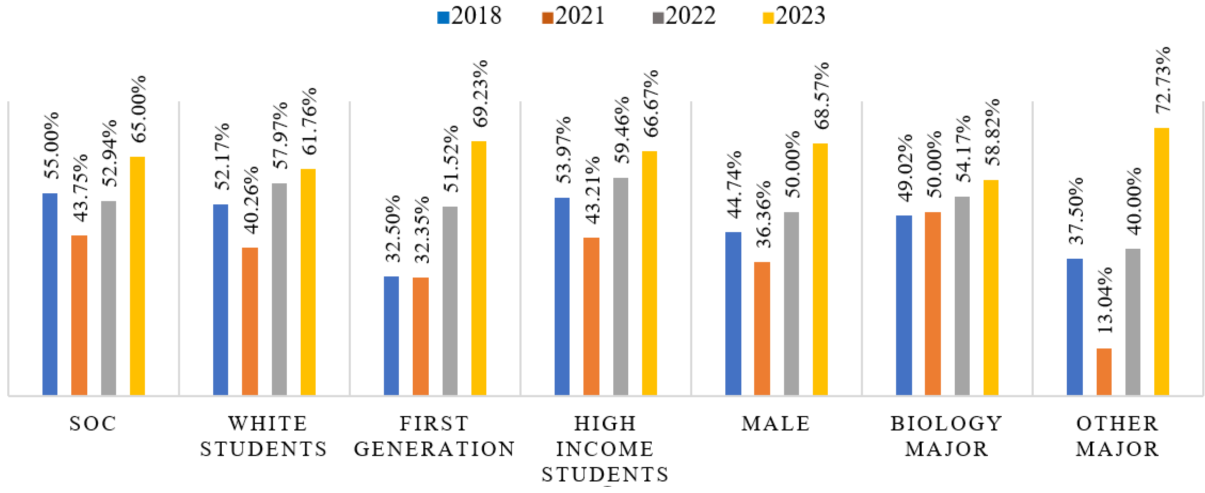


Source: Stackpool, Premarathna, Leahy

There is an important reliability limitation associated with using the PPG-1 method. Disproportionate impact findings based on a small number of students (fewer than 30) should be examined with some caution because they are subject to greater variability than seen with larger groups. The results observed for such small groups may fluctuate greatly when examined in the future (California Code of Regulations, 2022). We may conclude with caution based on the two methods, PPG and PPG-1, that three groups of students, Low Income, Female and Biology major experienced the disproportionate impact/academic equity gap in 2023.

The general trends in course passing rates suggest that for most student groups in our study, their passing rates increased during five years from 2018 to 2023 (Figure 4) and these groups either did not experience academic equity gap during this time interval (White students, High Income students) or they overcame academic inequities by 2023 (SOC, 1st Generation, Male, Other Major) after the 50% online and 50% face-to-face blended course model was implemented.

Figure 4: Groups of students with positive response on increased course structure



Source: Stackpool, Premarathna, Leahy

The noticeable decrease in the course passing rates for almost all groups in 2021 can be attributed to the challenges and rapid adjustments in teaching and learning caused by the COVID-19 pandemic. We suggest that the factors promoting student academic success and therefore contributing to positive trends in course passing rates, are connected to implementation of the evidence-based teaching approaches and increased course structure in 2022 and 2023. Among the possible factors that positively affected student achievement, the following factors are being considered:

- Increased amount of time students invested during their out-of-class study and therefore, increased student interaction with learning material.
- Additional help to a greater number of students was provided by the instructor during the mandatory study sessions, which is unfeasible with a lecture-based instructor-centered teaching model.
- Improved classroom culture through working in groups which promotes perception of class as a community. This helps underrepresented students (students of color and first-generation students) to overcome a lack of cultural responsiveness both in and out of the classroom, improve their academic performance, and their sense of belonging.
- Effective integration of the online and face-to-face components of the course into a coherent whole. The online course delivery components and face-to-face components complemented and enhanced one another. The 50% online and 50% face-to-face blended course model was found to be the most effective in increasing performance of students and decreasing the academic equity gaps in several groups of students including underrepresented students (students of color and first-generation students).
- Increased course structure improves efficiency of course delivery. Supplemental Instruction greatly favored the students' performance. However, it is not clear from our study what form of the Supplemental Instruction, the faculty-facilitated or peer-facilitated academic support system (MavPASS) resulted in higher positive.
- A strategy of learning through "desirable difficulties" was utilized to overcome the possible lack of students' preparation before mandatory study sessions. The low-stakes assignments which used generalization, elaboration, and reflection were provided before each mandatory session and graded timely. This also contributed to extensive student in-class engagement.
- The transfer of mandatory study sessions from virtual format (Zoom) in 2022 to the face-to-face format in 2023 promoted more effective communication (instructor-to-student and student-to-student), enhanced student engagement and performance from working in groups, and improved overall appreciation of this learning model.

3.3 Qualitative Summative Content Analysis

3.3.1 Sentiment Analysis

In the framework of the Participatory Action Research, the researchers and students were actively involved in the research project. Therefore, General Chemistry I students enrolled in Dr. Stackpool's class in spring 2022 and spring 2023 were invited to complete a survey during the last week of the semester to evaluate the helpfulness of each course delivery component, Question 8 (Table 8):

Table 8: Helpfulness of Course Components, Question 8

Components of course delivery	1 (*Least*)	2	3	4	5 (*Most*)
Online videos & lecture notes provided by your instructor	○	○	○	○	○
Mandatory study sessions	○	○	○	○	○
Optional weekly tutoring sessions	○	○	○	○	○
Review sessions before exams	○	○	○	○	○
MavPASS sessions	○	○	○	○	○

Source: Stackpool, Premarathna, Leahy

Students were also asked to provide suggestions to improve the General Chemistry I course related to the following three components integral to the flipped classroom design: 1) lecture delivery (virtual and asynchronous), 2) mandatory study sessions (virtual and synchronous (2022); face-to-face (2023)), and 3) optional tutoring sessions/review sessions (virtual and synchronous) and MavPASS sessions (face-to-face (2023)). As we can see in Table 9, the ratings of helpfulness reveal the same general trend for each of the two years: online lectures are rated as least favorable, optional sessions as most favorable, and mandatory study sessions in between.. As rating increases, we also see the standard deviation decreases, suggesting less varaibility in student attitudes.

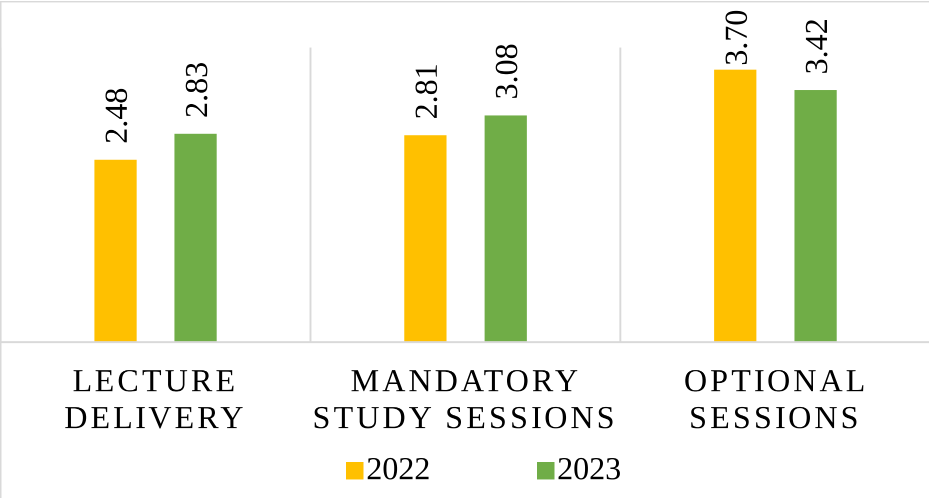
Table 9: Helpfulness of course delivery components

<table>
<tr><th rowspan="3">Years</th><th colspan="2">Lecture delivery</th><th colspan="2">Mandatory sessions</th><th colspan="6">Optional sessions</th></tr>
<tr><th colspan="2">Online lectures</th><th colspan="2">Mandatory study sessions</th><th colspan="2">Weekly tutoring sessions</th><th colspan="2">Review sessions before exams</th><th colspan="2">MavPASS sessions</th></tr>
<tr><th>Mean</th><th>SD</th><th>Mean</th><th>SD</th><th>Mean</th><th>SD</th><th>Mean</th><th>SD</th><th>Mean</th><th>SD</th></tr>
<tr><td>2022</td><td>3.29</td><td>1.39</td><td>4.03</td><td>1.32</td><td>4.11</td><td>1.17</td><td>4.69</td><td>0.67</td><td>---</td><td>---</td></tr>
<tr><td>2023</td><td>3.47</td><td>1.27</td><td>3.82</td><td>1.20</td><td>3.97</td><td>1.10</td><td>4.33</td><td>1.03</td><td>3.53</td><td>1.52</td></tr>
</table>

Source: Stackpool, Premarathna, Leahy

In an attempt to analyze the open-ended responses, researchers first conducted a sentiment analysis, in which each comment was rated on a 1-5 scale, from "very negative" to "very positive," respectively. The sentiment analysis (Figure 5) and the helpfulness ratings (Table 9) reveal similarities in student attitudes. It is important to note that in answering the open-ended questions, students were prompted to provide suggestions to improve the course and highlight its imperfections. Given that many comments were constructive in nature, responses trended toward a lower sentiment score. As a result, the helpfulness ratings may, in fact, be more representative of actual attitudes toward the course, but the open-ended feedback is still vital for continual improvement of course delivery.

Figure 5: Average sentiment rating of the course in 2022 vs. 2023



Source: Stackpool, Premarathna, Leahy

3.3.2 Inductive Thematic Analysis

Following the sentiment analysis, researchers conducted an inductive thematic analysis following the process as laid out by Braun and Clarke (Braun & Clarke, 2006). Researchers first familiarized themselves with the data, then generated initial codes to comprehensively summarize and differentiate responses. After the initial coding, themes were searched for, reviewed, and defined. After finalizing the themes, the data was summarized and themes were quantified in order to calculate relative frequencies for each of the three elements of the flipped classroom, as well as overall. These frequencies are summarized and reflected below in figure 6 and broken out into the following 4 core themes identified by the researchers:

A. The course design required too much time of students.
B. Students preferred lectures to be in-person.
C. Supplemental, review and mandatory study sessions were effective.
D. Optional sessions should be more flexible with scheduling.

Theme A: Course Design Burden

Many students found that the course design was taxing and demanded too much of their time. This was most common when referencing the recorded lectures, but some students also considered the worksheets for the mandatory study sessions to be too long. Specifically, students considered the length of the lectures to be difficult to follow, retain information, and prepare for mandatory study sessions.

> "Online lectures aren't bad but they're very long which makes it difficult to learn all material before the study session."

> "Not being able to finish the problems in class leads me to miss out on class time in other classes as I finish it."

Theme B: Preference for In-Person Lectures

Some students voiced a preference for in-person lectures which allow for more interaction with the instructor and course material. It is unclear to what extent this arose from personal preference as opposed to a belief that in-person lectures would be a more effective way to teach the course materials.

> "I feel that lectures should take place in person instead of the study sessions or have the study sessions be the videos instead."

> "[The mandatory study session] worked, I would rather have them be replaced with a lecture with participation."

Theme C: Non-Lecture Session Effectivity

Students found that the mandatory study sessions and optional sessions were largely effective and aided in both their understanding of the material and their subsequent grade in the course. Many students also noted that the design of these sessions was helpful in both diagnosing and correcting knowledge gaps.

> "The mandatory study sessions is where I learned almost all of my knowledge of chemistry. Being able to practice and talk with the professor helped build knowledge better than what I've been able to do by myself."

> "The optional tutoring sessions and MavPASS sessions definitely helped my grade, not only with the extra credit points, but also just with understanding the content better."

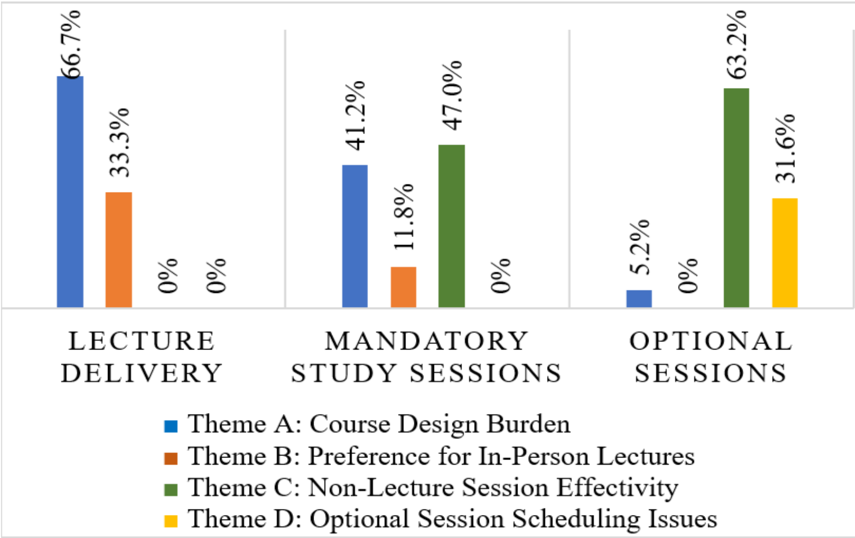
Theme D: Optional Session Scheduling Issues

Students noted that they preferred more flexibility with the availability of the optional sessions. This finding was also consistent for students who provided positive feedback for the utility of these sessions. However, for some students, these sessions appeared to conflict with their schedules for other courses or commitments.

"Make the review sessions during a time that is during class hours as it always fell during one of my other classes and I was unable to attend."

"I liked the optional tutoring sessions. I was not able to attend review sessions because I had other classes, but the review sheets were still helpful."

Figure 6: Relative frequencies for the theme elements.



Source: Stackpool, Premarathna, Leahy

Student surveys based on the traditional lecture format (Spring 2018) were compared with the Spring 2022 & Spring 2023 active learning format surveys. Student responses were then used for the course evaluations:

- Rating of the course as a whole
- Amount you learned in the course

Comparison of the main trends of the qualitative data and overall course ratings for three course versions are summarized in table 10.

Table 10: Main trends of the qualitative data, overall course ratings for 2018, 2022, 2023

Course model	Years	Core themes of the qualitative data	Overall course rating	Amount of knowledge learned
Lecture based face-to-face	2018	A. Students respect professor and believe that she genuinely wants them to learn. B. Some students want the pace of course slowed. C. Students want more interactivity. D. Students want translating tough concepts into more plain language ("dumbing it down") would be helpful.	M = 8.40, SD = 0.9	M = 8.40, SD = 0.9
Active learning based, blended	2022	A1: Students preferred to be in person and if meeting virtually, preferred to meet synchronously. A2: Students preferred to be virtual and/or asynchronous. B. The virtual meeting space specifically limited interstudent interaction, facilitation, and discussion. C. Many students noted that they had trouble keeping up with the work and could benefit from more direct supervision. D. Optional meetings were largely effective and valued by students, especially for examination preparation	M = 6.63, SD = 2.60	M = 6.97, SD = 2.30
	2023	A. Course design demanded too much of students' time. B. Preference for in-person lectures. C. Supplemental, review and mandatory study sessions were largely effective. D. Optional session scheduling issues: more flexibility with the availability of the optional sessions.	M = 7.59, SD = 2.22	M = 7.85, SD = 1.99

Source: Stackpool, Premarathna, Leahy

Table 10 reveals the highest student rating of the course in 2018 and the lowest in 2022. Noticeable improvement in the overall course rating and amount of knowledge students learned in the course in 2023 vs. 2022 can be attributed to a format change of the mandatory study sessions – from virtual, Zoom (2022) to face-to-face sessions (2023).

We anticipated that the active learning format with flipped classroom would essentially address most of the themes found in student evaluations in 2018 by allowing students to study at their own pace and be more interactive by discussing more directly with the instructor and other students. However, we found the opposite with the overall course ratings for 2022 and 2023 being lower compared to 2018 (Table 10). This decrease may reflect a resistance of some students to active learning, a more challenging model of learning, which makes them feel like they're learning less. Active learning requires students to put in more time preparing for each study session and more effort during class to stay current with the pace of the course. "What the students did not say directly, but something to which they were alluding, was that they had to learn at the rate which the classroom was going rather than 'letting it slide' and cramming at the last moment" (Aronson & Arfstrom, 2013).

This decrease in course rating also suggests that the students may have a misperception of the quality of their own learning. This conclusion is consistent with the study conducted by Louis Deslauriers and his team (Deslauriers et al., 2019). According to Logan McCarty:

"The students in the active-learning classroom scored higher on the test of learning, but their perception of their feeling of learning was lower. So in the active-learning classroom, they rated the quality of the instructor lower. There was a negative correlation between how much students learned, as measured by the test, and how they felt they were learning, as measured by the survey" (Explorations of Active Learning, 2022).

Such a negative correlation may require a change in the evaluative process at the institutional level. Evaluation of the instruction quality should not only depend on student feedback, but on observers that go into the classroom and rate the kind of active learning that's being used and how it's being used (Explorations of Active Learning, 2022).

By analyzing the qualitative data and student satisfaction, another conclusion can be made. It is important to address students' perceptions around active learning at the beginning of the semester, before course delivery has begun. We need to make it clear to students why we are offering active learning format and demonstrate how research suggests active learning benefits students versus traditional lecture.

4. Conclusion

The redesign of a gateway General Chemistry course in favor of a blended high structure format with a flipped classroom teaching/learning model in conjunction with the two forms of Supplemental Instruction can improve instructional delivery and student performance by providing additional and more focused help to a greater number of students which is not feasible with a fixed class time of lecture-based instructor-centered teaching model. The evidence-based teaching approaches implemented in 2022 and 2023 (the flipped classroom teaching/learning model and Supplemental Instruction (faculty-facilitated learning enhancement tutoring and peer-facilitated academic support system - MavPASS)) complemented and enhanced one another. Our research confirmed that high structure courses positively impact student performance (Eddy & Hogan, 2014; Freeman et al., 2014). A blended high structure course format when offered in 50% online 50% face-to-face proportion (spring 2023), have shown a better effect on the student academic performance with a meaningful decrease in C-DFW grade rate by 9.69% and 21.64% as compared with control sections 1 (2018) and control section 2 (2021) respectfully. As it was anticipated in our previous study (Stackpool et al., 2023), transition of the mandatory study sessions from online to a face-to-face format and implementation of another form of Supplemental Instruction, (MavPASS) led to further improvement in student performance and decrease in C-DFW grade percentage by 5.52% in spring 2023 compared with spring 2022. The blended high structure course format also leads to elimination of the academic equity gaps within several groups of students including students of color and first-generation students and offers an effective strategy to better serve a steadily diversifying twenty-first-century student population.

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Informed Consent

The authors have obtained informed consent from all participants.

Conflict of Interest

The authors declare that there is no conflict of interest.

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