Undergraduate Student's Voices and Achievement in a Purposefully Designed Calculus Active Learning Setting

Nigar Altindis
University of Alabama

Karen J. Graham
University of New Hampshire

Jerome Amedu
University of New Hampshire

Pei Geng
University of New Hampshire

We explore undergraduate students' perceptions of and the impact of implementing active learning in calculus recitations. Analysis of Likert-scale items indicate that speaking up in recitation helps clarify students thinking, suggesting that calculus instructors should create opportunities for students to speak up in the classroom. Qualitative analysis of two open-response questions indicates an increasing trend over time of students responding that working on problems in small groups was one of the most helpful aspects of recitation. Although students responded that dissatisfaction with group work was one of the least helpful aspects of recitation, this response was never as prominent as group work being the most helpful aspect. An independent two-sample t-test on students' course grades indicate no statistically significant difference (p = 0.14) between the treatment group (active learning) and control group. Results suggest that active learning with structured group discussions enhances student engagement and collaboration in learning Calculus concepts.

Keywords: Active Learning, Calculus, Collaborative Small Groups

Introduction

Undergraduate Calculus courses are foundational for all STEM disciplines. Success in the course is critical to retention since many students who struggle tend to leave STEM majors (Bressoud, et al., 2015). For students who are underrepresented in STEM, like women and people of color, having positive learning experiences in Calculus courses has been especially linked to their success and retention in STEM-related careers (Ellis, et al., 2016; Laursen et al., 2014). To address these challenges, over the last few decades, mathematics departments nationwide have invested in revamping their calculus courses (Rassmussen et al., 2019; Smith and Funk, 2021). These revamped courses include implementing a more student-centered culture that values active learning to improve student learning and engagement with mathematics (CBMS, 2016; Uhing et al., 2021).

Based on these recommendations and with support from an NSF grant (Award No. 2013427) we have substantially transformed the teaching of Calculus over the last four years. The Calculus I course at our institution is offered in the lecture-recitation format. All lectures and recitations are closely coordinated, following a common curriculum, calendar, and assessments. Starting in Spring 2022, we restructured our Calculus I course by introducing evidence-based practices. In recitations, students work in small groups collaboratively solving problems and a graduate teaching assistant (GTA) and an undergraduate learning assistant (LA) circulate the room and support student learning by responding to questions, orienting students to learning resources, and encouraging students to collaborate, share, and present their ideas. In revising the course structure and recitation materials we adopted The Conference Board of the Mathematical Sciences (CBMS) statement that defines active learning as "classroom practices that engage students in activities, such as reading, writing, discussion, or problem-solving, that promote higher-order thinking" (CBMS, 2016, para. 1). This paper highlights the voices of the students and the potential impact on their learning throughout four semesters of implementation.

Literature Review and Theoretical Orientation

The Impact of Active Learning in Undergraduate Mathematics Classrooms

Research has consistently shown that active learning settings, broadly defined, positively impact both students' experiences (Uhing et al., 2021) and academic performance (Fuchs & Sahmbi, 2024). Freeman and colleagues (2014) specifically found that students in active learning environments outperformed their peers in traditional settings, with an average performance increase of 6%. Additionally, students in traditional, lecture-based classrooms were 1.5 times more likely to fail compared to those in active learning environments.

Delving into the reasons behind these positive outcomes, scholars report that active learning enhances comprehension and promotes higher achievement, fosters conceptual understanding (Code et al., 2014; Maciejewski, 2016; Roop et al., 2018), and reinforces mathematical competency and confidence (Kogan & Laursen, 2014; Lenz, 2015). Such findings indicate the effectiveness of active learning in mathematics classrooms and its potential to reduce failure rates while improving overall student engagement and performance.

Students Voices and Experiences with Active Learning Calculus Course Design

Research has consistently documented students' perceptions and experiences with active learning in mathematics courses, with most students indicating a high level of engagement and perceiving these courses as beneficial to their learning (Bowers et al., 2019; Reinholz, 2018; Weurlander et al., 2017). Collaborative group work has effectively promoted student engagement and success in Calculus classrooms (Hitt & Dufour, 2021; Code et al., 2014). However, some studies have reported student resistance to active learning methods (Tharayil et al., 2018), highlighting the need for continued investigation into students' perceptions of active learning environments in Calculus courses.

Even when students were neutral or did not favor the active learning classroom settings, they still found the course structure beneficial for their understanding of mathematics (Smith & Cardaciotto, 2011; Rosenthal, 1995; Weurlander et al., 2017). These findings suggest that while active learning generally enhances student outcomes, there is variability in how students perceive and respond to these methods. This emphasizes the importance of understanding students' voices and integrating them into active learning designs that are tailored to students' needs.

Active Learning

Active learning is defined as a method of teaching mathematics through student-centered pedagogies (Faust & Paulson, 1998; Weiman, 2014). It involves students engaging with the learning process in ways that require active participation and involvement (Prince, 2004), and it is a pedagogy that immerses students in the practice of doing mathematics (Fuchs & Sahmbi, 2024). In this context, active learning is about the practice of students' engagement, instructional routines, and the learning process and its outcome. This study aims to explore students' perceptions of and the impact of implementing active learning in undergraduate calculus recitations. With the following questions: (1) What are students' perceptions of an active learning environment in Calculus 1 recitations? (2) Is there a difference in students' final course grades before and after the introduction of active learning in calculus recitations?

Method

Context of the Study

This project focused on active learning in Calculus I as part of a larger research and development project to revamp introductory STEM courses at a research-intensive university in the northeastern United States. Starting in Spring 2022 a purposefully designed student-centered. active learning approach was implemented in the recitations using a particular structure (brief introduction/review by the GTA, group work on problems, student presentation of solutions), researcher-created activities, and undergraduate learning assistants working with the GTAs to facilitate discussion. Prior to Spring 2022, most of the recitation sections were instructor-centered, with whole group discussions led by the GTA; they highlighted problems from the textbook similar to the assigned homework, with the GTA answering student questions related to the concepts being covered in the lecture.

Data Collection

At the end of each semester, we collected survey data from students enrolled in the Calculus I course (a total of 694 students across four semesters, 154 students in Spring 2022, 212 in Fall 2022, 159 in Spring 2023, 169 in Fall 2023). The survey was comprised of seven Likert scale questions and several open-ended questions. Students were asked to respond on a 5-point Likert Scale (5- strongly agree to 1-strongly disagree) to each of the following statements: (1) The recitations helped me learn Calculus better (Help_learn); (2) I would like other courses to have small group work available as an option (SG_Other_Courses); (3) Ideas in this course became clearer after I heard other students in my small group explain them (S_Ideas); (4) I would recommend group work at Calculus recitations to other students (SW_Calculus); (5) When I spoke up in recitations, it helped me clarify my thinking (SR_Helped); (6) I looked forward to coming to Calculus recitation sessions (CR_Sessions); (7) I collaborate on Calculus related work with people from my group outside of class time (CC_Group).The two open-response questions analyzed for this paper are: (1) Please comment on the aspects of the recitations you think were most helpful for your learning; and (2) Please comment on the aspects of the recitations you think were least helpful for your learning.

Method of Analysis

The current analysis focuses on students' perceptions of the structure of the active learning environment in the recitation sessions and how it influenced their learning experiences both qualitatively and quantitatively. By analyzing students' final course grades, we aimed to examine the impact of the active learning approach on students' course achievement. Specifically, a two-sample t-test is applied to the final course grades to compare the traditional learning and active learning. Moreover, correlation analysis is conducted on the Likert scale survey questions to study students' perceptions about the active learning environment. In addition, we conducted a qualitative analysis to identify the aspects of the active learning environment that students found most beneficial and the factors that contributed to their engagement and motivation.

To analyze the open-ended responses, two members of the research team developed a codebook using both theory and data-driven approaches as described in DeCuir-Gunby et al. (2011). The codebook contained code labels, code definitions, and example responses to describe the individual codes. First, theory-driven (a priori) codes were developed based on Uhing et al. (2021) in their analysis of students' learning experiences with active learning mathematics in Precalculus through Calculus courses at six institutions. The three broad codes in this first stage were helpful instructional practices, positive recitations experiences, and negative recitation experiences. During the second stage, data-driven (emergent/inductive) codes were developed to capture core issues that repeatedly showed up in student responses but did not fit under existing a priori codes. The researchers first coded the data independently, then they met to compare results; discrepancies were resolved by consensus. A summary of the final codes is presented in the results section below.

Results

Reliability Measures

We established the reliability of the perception of student active learning for the seven Likert-scale items (Altindis & Oyeniran, 2024) for both 2022 and 2023. Reliability measures (estimated reliability within the range of 0.81 to 0.87; Cronbach alpha 0.81 for both years; omega alpha 0.85 for 2022 and 0.84 for 2023) indicated that the seven items and the whole scale are equally reliable (Van den Brink & Mellenbergh, 1998). Additionally, we proved that the survey items measure a single construct: the students' perception of active learning (c.f., Altindis & Oyeniran, 2025).

Correlation Analysis of Students' Perception

With the Likert scale data from the 7 survey questions, Pairwise Spearman correlations were computed for each of the four semesters that implemented active learning activities. All the pairs of the seven survey questions produced positive correlations. Table 1 shows the Spearman correlations of those pairs with correlation value greater than 0.30 for each semester. Across all the four semesters, S_Ideas and SW_Calculus produced the largest correlation compared to all other pairs, followed by SG_Other_Courses and SW_Calculus.

Table 1 Pairwise Spearman correlations of the seven Likert scale survey questions (Likert survey, pairs > 0.30)

Scales	Spring 2022	Fall 2022	Spring 2023	Fall 2023
S_Ideas & SW_Calculus	0.671	0.679	0.724	0.624
SG_Other_Courses & SW_Calculus	0.526	0.562	0.503	0.578
Help_learn & SW_Calculus	0.460	0.539	0.335	0.539
Help_learn & CE_Sessions	0.434	0.489	0.420	0.455
SW_Calculus & SR_Helped	0.402	0.436	0.307	0.494
S_Ideas & SG_Other_Courses	0.382	0.420	0.407	0.515
S_Ideas & CE_Sessions	0.322	0.407	0.306	0.316
SR_Helped & CE_Sessions	0.316	0.442	0.431	0.467
Help_learning & S_Ideas	0.312	0.411	0.359	0.402

The correlation coefficients between the scales S_Ideas (students' perception of clarity of ideas after group discussions) and SW_Calculus (students' willingness to recommend group work in Calculus) across four semesters are as follows: 0.671, 0.679, 0.724, and 0.624. These findings suggest a robust positive relationship between how much students feel that group discussions clarify their understanding of Calculus concepts and their likelihood to recommend group work. This trend has been consistent over the four semesters, showcasing the value of group work in supporting students' learning experiences.

The correlation coefficients between the scales SG_Other_Courses (students' preference for having small group work available in other courses) and SW_Calculus (students' willingness to recommend group work in Calculus) across the four semesters are as follows: 0.526, 0.562, 0.503, and 0.578. This means that students with a positive experience with group work in Calculus recitations are moderately likely to prefer similar group work opportunities in other courses. This suggests that successful group work experiences in one course can positively influence students' attitudes towards group work in other courses.

Students' Perception of Active Learning

We calculated the mean values of survey scales for each semester to analyze the overall trends in students' perceptions of active learning, examining whether these perceptions increased or decreased over the four semesters (Table 2).

Table 2. Mean Scores and Standard Deviations of Students' Perceptions of Active Learning Across Four Semesters

	Spring 22	Fall 22	Spring 23	Fall 23
Help_learn	4.39 (0.778)	3.98 (0.920)	3.89 (1.032)	3.86 (0.999)
SG_Other_Course	4.04 (0.858)	3.88 (0.942)	3.71 (0.895)	3.93 (0.920)
S_Ideas	3.83 (0.932)	3.54 (1.036)	3.49 (1.030)	3.53 (1.023)
SW_Calculus	4.14 (0.905)	3.86 (0.974)	3.74 (1.026)	3.96 (0.937)
SR_Helped	3.95 (0.858)	3.72 (1.002)	3.82 (0.889)	3.78 (0.928)
CR_Sessions	3.37 (1.060)	3.06 (1.125)	3.02 (1.090)	3.14 (1.053)
CC_Group	2.65 (1.300)	2.63 (1.368)	2.60 (1.287)	2.72 (1.318)

Overall, responses to the 7 survey questions indicated that while students generally find value in small group work and recommend it to others, their feelings about how much it helps them learn and clarifies ideas have gradually declined. The "CR_Sessions" and "CC_Group" scores indicate that students are less enthusiastic about attending recitations and collaborating outside of class, suggesting that the structure or effectiveness of these sessions may need re-design to re-engage students. Most importantly, students' realization that speaking up in recitations helps clarify their thinking, suggests that fostering more opportunities for student participation could be beneficial.

The graphs in Figure 1 provide the results for the qualitative coding of two open-response questions (aspects that were most helpful and aspects that were least helpful) and represent the number of students who responded in each subcategory across the four semesters. It should be noted that student responses may fall into more than one category. Subcategories of responses to the question about what aspects of recitations were most helpful were further subdivided into two broad categories: (1) helpful instructional practices that include working on problems in small groups (GW), presenting solutions (PW), creating individual help space (IHS); and (2) positive experiences with group work/recitation that include working on problems (WP), TA/LA support (TAS), small class size/community building (SC). Responses to the survey question asking about aspects that were least helpful were subdivided into the following three categories: dissatisfaction with group work (DGW), concerns about recitation work/content (CRW), and class format & scheduling (CF). From the graphs we see an increasing trend over time in students responding that group work (GW) was one of the most helpful aspects of the recitations. We also note that even though students noted that dissatisfaction with group work (DGW) was a least helpful aspect, the number was consistent across the semesters and not as prominent a response compared to group work being one of the most helpful aspects.

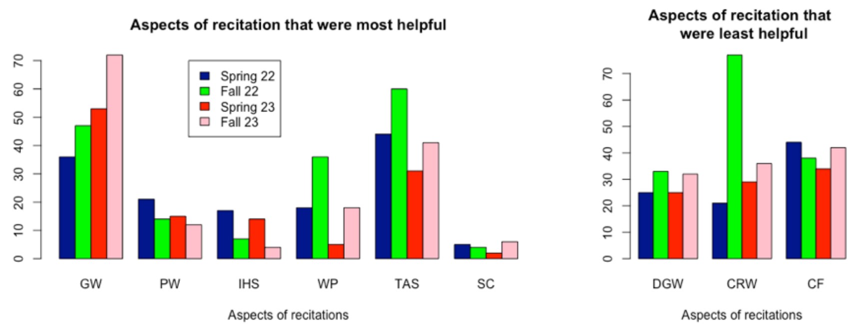

Figure 1. Distribution of codes for student responses to two open-response questions by semester

Comparing Student Achievement in Calculus

This study aims to determine if there is a significant difference in students' final course grades before and after the introduction of active learning in calculus recitations. To assess this, we collected data from students enrolled in Calculus during the following semesters: Fall 2021, where a traditional instructor-centered learning approach was employed, and Spring 2022, Fall 2022, Spring 2023, and Fall 2023, where an active learning approach was implemented.

Through preliminary examination, we found that there was a statistically significant difference (p-value < 0.001) in student achievements between the Spring semesters (n=402, mean 2.10 and sd. 1.25) and Fall semesters (n=456, mean 2.43 and sd. 1.22) where the active learning approach was implemented. Therefore, to reduce confounding effects and ensure a fair comparison, we focus on the analysis in the Fall semesters for the effect of the active learning approach with group work in recitations.

To ensure the validity of combining the data from the two Fall semesters (Fall 2022 and Fall 2023), an independent two-sample t-test showed no statistical significance (p-value = 0.84) in the difference in student achievement between the two semesters. Therefore, we combined the data from Fall 2022 and Fall 2023 to serve as the treatment group for active learning, while Fall 2021 serves as the control group.

The treatment group utilizing active learning shows an increase in average course grades (n=456, mean 2.43, sd. 1.22) compared to the control group (n=226, mean 2.31, sd. 1.43). To assess the effect of the active learning approach, a one-sided independent two-sample t-test produced a p-value of 0.14 between the control and treatment groups, indicating that the treatment's effect is statistically insignificant at the 0.05 significance level. Additional data from future semesters could further enhance the understanding of the treatment's impact. Figure 2 below shows the grade distributions for two types of learning methods.

We note that instructors in the experimental groups were not the same as in the control groups. However, the course materials, homework assignments, tests and exams, and grading policies were used uniformly by all instructors in the control and treatment groups.

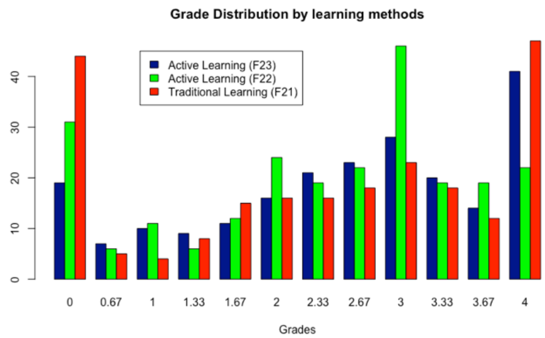

Figure 2. Grade distribution for Fall 2021 (traditional format), Fall 2022, and Fall 2023 (active learning format).

Discussion

We found a strong positive correlation between students' perceptions of the value of group discussions in clarifying their understanding of Calculus concepts and their likelihood to recommend group work to their peers, confirming previous work (Uhing et al., 2021). This indicates that as students engage more deeply in group discussions and gain clarity on calculus concepts, they recognize the benefits of collaborative learning and are more inclined to promote small group work in recitations and other courses.

These results are supported by the coding of the two open-response questions. There was an increasing trend over time of students responding that working on problems in small groups was one of the most helpful aspects of recitation. This increase over time might be a natural result of the instructional team adapting to the more student-centered process. Responses in the dissatisfaction with group category might be more related to how the groups were structured rather than group work not being helpful, e.g., the student did not like "switching groups multiple times", or how groups were assigned "random groups – I would have learned the most from my first group, but it got switched." Student concerns about recitation work/content (CRW) are consistent with results from the SEMINAL survey (Uhing et.al (2021). That is, students found some of the recitation work unrelated to the lecture or course assignments and wanted more practice, "For me recitation should be about practice problems and solving them in order to get used to them", "the recitation work felt incredibly out of sync and off topic compared with what we were learning in the main course."

An independent two-sample t-test indicated no statistically significant difference ($p = 0.14$) in students' course grades between the treatment group (active learning setting) and the control group at the 0.05 significance level. These findings do not support the claim that students participating in active learning environments achieved better final grade outcomes in Calculus compared to those in traditional lecture-based settings. Instead, we argue that we think there are other variables that affect students' achievements in calculus courses, yet our test does not measure them.

In summary, the results suggest that integrating active learning, particularly through structured group discussions, can enhance the student learning experience by promoting engagement and collaboration in understanding Calculus concepts. These findings necessitate further exploration into the long-term effects of active learning on student success and motivation in STEM courses.

Acknowledgments

This research was supported by the National Science Foundation, Award No. 2013427. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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