Student-Supported Groupwork on Vertical Whiteboards: The Impacts on Students and Peer Tutors in a Calculus I Class

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ABSTRACT
Simon Fraser University in Vancouver, Canada offers two introductory calculus courses designed for students enrolled in science and engineering programs. Students identified as needing additional support based on their admission grades take the version of the course where students meet weekly for four hours instead of three.
A new approach for the fourth hour was introduced in Fall 2019 splitting the class into smaller sections of 20-40 students to work in small groups on vertical whiteboards under the supervision of the instructor, complemented by peer tutors. This format introduces an active learning element that improves student performance and attitude. The project was first implemented in Fall 2019, although interrupted due to Covid-19. After returning to the in-person classroom, the whiteboard seminar program was reinstated. In Fall 2022 and Spring 2023, survey feedback was collected from both students and peer tutors for a more holistic perspective on the program.

In this study, the results of these surveys are analyzed, focussing on four areas of measurement: students' satisfaction, learning calculus concepts and problem-solving techniques, the contribution of the instructor, and the contribution of the peer tutors. Exploratory factor analysis revealed three latent variables underlying student survey responses. The survey results suggest that interactions with the instructor, peer tutors, and active learning activities all contributed to students' enjoyment of the course and their perceptions of their own learning. We compared students' final course grades from Fall 2018, where the fourth hour was devoted to lecture before the program was implemented, to Fall 2019 and 2022. The data shows a decrease in the percentage of students failing the course and an increase in those earning A's and B's since the program's implementation. Additionally, survey results show that replacing a typical lecture-style hour with a whiteboard seminar improved students' attitudes and perceptions of the course.
Keywords: Collaboration, whiteboards, problem-solving, peer tutor.

1 INTRODUCTION
In many North American postsecondary mathematics courses, students in their first and second years often have few learning opportunities beyond attending three weekly lectures and visiting drop-in consulting centers, called Workshops, where they can meet with instructors and teaching assistants during office hours. Due to large class sizes, hours during lectures have limited interaction and engagement. Furthermore, workshop attendance is often low and restricted to a small proportion of students who repeatedly attend, with an increased audience before tests. Although workshops aim to provide personalized feedback through targeted question sessions for students to enhance their understanding and performance, their effectiveness may be limited for students that are inadequately prepared or have biased perceptions or attitudes toward this type of environment. The workshop environment requires students to know when they do not understand something and puts the onus on the student to reach out for help. As a result, exploring effective strategies to promote student preparation and engagement is crucial to maximize the potential benefits of tutorials and workshops (Overton, 2014).

Peer tutoring refers to a teaching approach in which students take an active role in the learning process by teaching their fellow classmates (Evans et al., 2001). Studies have shown that peer tutoring can provide valuable support to students in a variety of ways, including facilitating group discussions, clarifying concepts, and providing personalized feedback (Falchikov, 2001; Andrews & Clark, 2009). Peer tutoring can also help students to develop a deeper understanding of course content and improve their study skills (Andrews et al., 2011). Moreover, the use of peer tutors can improve student engagement and satisfaction with the course, leading to increased retention rates (Gunn et al., 2017).

However, there are some challenges associated with the use of peer tutoring as a supplement to lectures. The effectiveness of peer tutors may depend on their level of training, experience, and knowledge of the course content (Baker & Lattuca, 2010). Moreover, some students may feel uncomfortable seeking help from their peers, and there may be concerns about the quality and consistency of the support provided by peer tutors (Roscoe & Chi, 2007). Despite these challenges, the effective utilization of peer tutors as a supplementary resource to lectures has demonstrated promising results in enhancing student learning outcomes in higher education.

Kouzniak et al. introduced a novel modification to traditional tutorials and workshops in the form of "whiteboard seminars" (Kouzniak et al., 2021a; Kouzniak et al., 2021b). Whiteboard seminars are based on the La Trobe

method (Seaton et al., 2014), where students work in groups on vertical whiteboard surfaces to solve mathematical problems related to material recently covered in lecture. This choice-affluent environment allows students to access resources from their peers, including those in other groups, as well as peer tutors and instructors. Kouzniak et al. conducted a study on the implementation of these seminars at a public university in Canada and reported the findings from surveys completed by students, as well as observations from the instructor and peer tutors. They framed their work in the context of Koichu's choice-affluent learning environments (Koichu, 2018), where students have access to various options to enhance their problem-solving abilities. The study indicated that students who participated in the seminars displayed a higher level of engagement than their peers, which correlated with improved grades in the course. Additionally, these students exhibited a positive attitude towards mathematics and collaborating with their peers.

In this study, we aimed to expand upon the previous work of Kouzniak et al. by conducting a thorough statistical analysis on a new dataset, and by engaging in further discussions with both peer tutors and students. In addition, we assessed the impact of the learning environment on students' performance in the course.
Our analysis identifies the presence of three latent variables that account for the majority of the survey results. By comparing our statistical findings with the survey questions, we identified three variables that were indicative of the results: (1) success in the whiteboard seminars, (2) a combined impact of the instructor and peer tutors, and (3) student enjoyment from working with whiteboard/chalkboard surfaces. Further analysis was conducted to verify the presence of these factors and explore the connections between students' responses. Our findings suggest that enjoyment of learning in the seminars results from a combination of the instructor and peer tutors' contributions, as well as the students' satisfaction in working on vertical whiteboard surfaces. About 94% of the students' responses supported this result. An analysis of students' final grades from three semesters indicates a positive impact of whiteboard seminars on academic outcomes. Specifically, course offerings that included whiteboard seminars saw a reduction in the percentage of students who received a failing grade, while the proportion of students who earned A's and B's increased compared to course offerings without it. Overall, the findings of this study suggest that replacing a traditional lecture-style hour with a whiteboard seminar can lead to significant improvements in both academic outcomes and student engagement.

2 METHODOLOGY

Student-centered learning environments, which allow students to have a more active role in their learning process, have been found to enhance their motivation, engagement, and overall academic achievement. One approach to achieving a student-centered environment is through providing students with choices in their learning process, such as the choice of problem or the mode of engagement. Studies have shown that students who have the ability to make choices in their learning process exhibit higher levels of intrinsic motivation and are more likely to engage in deep learning strategies. Furthermore, the presence of instructors and peer tutors can serve as valuable resources to assist students in their decision-making process and facilitate their learning. (Deci & Ryan, 1985; Deci et al., 1991; Reeve & Jang, 2006; Vallerand et al., 1992).

The whiteboard seminars discussed in our study exemplify a student-centered learning environment. Whiteboard seminars are a weekly program that has been developed specifically for first-year calculus students at Simon Fraser University who have not achieved high scores in high school or university pre-calculus courses. These students often face significant challenges when it comes to grasping calculus concepts and may feel detached from the course material. The cohort is divided into groups of 20-40 students who attend their mandatory seminar hour at various scheduled times throughout the week. During these seminars, students are randomly assigned to groups of three to four individuals and given a set of 10-15 questions to work on. These questions are carefully selected to include both entry-level questions and more sophisticated tasks, which require students to think critically, make connections, and develop their problem-solving skills. To tackle these problems, students are expected to properly analyze the conditions of each problem, think of a relevant mathematical concept that can be applied, and develop an appropriate solving technique. The questions are distributed to students a week prior to the seminars so students may opt to prepare for their group work time in advance. Within the seminars, each group is provided with a vertical erasable surface to promote collaboration and iteratively develop complete solutions for the problems. One important aspect of the seminars is that each complete solution is presented by a different group member to the instructor, encouraging participation and collaboration among the group. Additionally, both peer tutors and the instructor are available to provide guidance and feedback during the problem-solving process. In this study, we conducted a thorough analysis of the influence of seminars by examining students' observations during the seminars and their performance in course exams.

Peer tutors were carefully selected for the whiteboard seminars to ensure that they were highly capable and qualified to assist their fellow students. Peer tutors must have previously completed the calculus course with at least an A-level grade and have participated in various volunteering activities. Candidates were then interviewed

to ensure all peer tutors had excellent communication skills. To enhance the peer mentors' effectiveness, training was provided prior to the start of the seminars. This training included a mock seminar to provide an experimental environment for the peer tutors to practice their skills and receive feedback from the instructors. The aim of the training was to improve the peer tutors' ability to communicate mathematics with students, provide help and clarification without solving the problems for the students, and create a friendly and supportive environment. By preparing the peer tutors in this way, we sought to create an environment that would foster effective communication and collaboration between students and peer tutors, while ensuring the students were the ones answering the seminar problems. We utilized peers' observations from the seminars to analyze the impact of the seminars on student performance, as well as the effects on the peers themselves and potential impacts on their future engagements.

Statistical analysis plays a critical role in analyzing students' responses to participation in various learning environments. Through statistical analysis, researchers can identify underlying patterns, factors, and relationships that are not immediately evident from raw data. This allows for a more in-depth understanding of the factors that influence students' engagement, performance, and satisfaction in the learning environment. Moreover, statistical analysis can help researchers identify areas of improvement, evaluate the effectiveness of different interventions or teaching strategies, and make data-driven decisions to enhance student learning outcomes. In our statistical analysis, we identified several significant factors that contribute to the success of the whiteboard seminars. Our findings emphasize the importance of the instructor and peer tutors in facilitating student learning, as well as the students' preference for working on vertical whiteboard surfaces.

2.1 Survey Data

The whiteboard seminars were started in the Fall semester of 2019, halted due to the COVID-19 pandemic in Spring 2020 but resumed in Fall 2022. The students and peer mentors were surveyed in Fall 2022 and Spring 2023 for this study. The Calculus I course offered in these semesters consisted of three weekly lecture hours and a whiteboard seminar hour, where students tackled problems on vertical whiteboards positioned around the classroom. The efficacy of whiteboard seminars held in Fall 2019 and Spring 2020 was previously analyzed and discussed in (Kouzniak et al., 2021a) and (Kouzniak et al., 2021b). In our study, we focus on the responses of students in the surveys conducted during Fall 2022 and Spring 2023. We also compare our findings with the results of previous surveys.

To prepare for the whiteboard seminars, students were given seminar problems in advance and were asked to attempt them prior to the seminar. Two of the problems, selected by the instructor as most relevant to the course concepts, were marked for completion at the end of each seminar week, but not for correctness. This approach aimed to encourage students to engage with the seminar problems and familiarize themselves with the relevant concepts prior to their designated seminar hour. The goal of this setup was to enhance students' learning experience by ensuring they were adequately prepared to participate in the seminar discussions.

During the Fall 2022 and Spring 2023 semesters, surveys were administered to gain insight into student perception of the whiteboard seminars. Student surveys were administered online at the end of each semester prior to final exams using the SurveyMonkey service, and students' responses were submitted anonymously. We retained the majority of questions from past conducted surveys in Fall 2019 and Spring 2020. Analysis of survey results was conducted on 15 questions that were asked in both semesters:

Question 1. Interaction with the instructor/seminar leader in the seminars helped me see her as approachable.
Question 2. Interaction with the instructor/seminar leader in the seminars helped me to understand the course material better.
Question 3. My communication with the instructor encouraged me to ask more questions and get help.
Question 4. The seminars were a joyful experience.
Question 5. The seminars were a stressful experience.
Question 6. The activities in the seminars deepened my understanding of calculus concepts.
Question 7. The Calc Connect Peers were approachable.
Question 8. The Calc Connect Peers were able to answer all questions.
Question 9. The Calc Connect Peers helped me to understand the process of problem solving when I did not know how to approach a question.
Question 10. What impact did the Calc Connect Peers have on your experience in this class?
Question 11 It was easy for me to ask questions during the seminars.
Question 12. I enjoyed working on the non-permanent vertical surfaces (whiteboards or chalkboards).
Question 13. I felt fulfilled, heard, and happy during the seminars.

Question 14. Discussing the questions with other students (e.g., talking back and forth, debating, comparing ideas) helped me learn in the seminars.
Question 15. Would you enroll in another class with whiteboard/chalkboard activities?

All the survey questions were multiple choice, ranging from 1 (strongly disagree) to 7 (strongly agree), except for questions 6, 9, 13, and 15, which had a 5-point scale ranging from 1 (negative response) to 5 (positive response). Question 5 was reverse scored, meaning that 1 indicates strongly agree and 7 indicates strongly disagree. This question was used to control for response bias.

Table 1: Groups of questions and measuring factors.

Groups	Factor to Measure	List of Questions
GP1	*students' satisfaction*	*Q4, Q5, Q12, Q13, Q15*
GP2	*learning calculus concepts and problem-solving techniques*	*Q2, Q6, Q9, Q11, Q14*
GP3	*contribution of the instructor*	*Q1, Q2, Q3*
GP4	*contribution of peer tutors*	*Q7, Q8, Q9, Q10*

We aimed to measure four distinct factors based on the students' responses: students' satisfaction (GP1), learning calculus concepts and problem-solving techniques (GP2), the contribution of the instructor (GP3), and the contribution of peer tutors (GP4). To study these factors, we categorized survey questions to assess each of these parameters. Table 1 describes the list of questions in each of such groups.

To gain a more comprehensive understanding of the students' perceptions and experiences with the whiteboard seminars, we calculated new variables for each of the four groups by averaging the loadings of different items within each group. To calculate the descriptive statistics for GP1-GP4, we performed a transformation on the original 5-scale questions and converted them to 7-scale questions. Q5 was reverse scored, so we applied a reversed transformation to compute the new variables. By analyzing the new variables using descriptive statistics and correlation values, we were able to examine each factor's impact more directly. This analysis provided a deeper insight into the students' satisfaction, learning, and the role of the instructor and peer tutors in the whiteboard seminars.

The statistical software SPSS and R were employed to apply exploratory factor analysis (EFA) and principal component analysis (PCA), and to identify latent factors based on the mean eigenvalue cut-off of approximately 0.9. The identified latent factors include the success of whiteboard seminars, the difference in contributions between peer tutors and the instructor, and students' enjoyment of working on the vertical whiteboard. The correlation matrix, the total variance explained by the latent factors, and item loadings were also investigated. Next, hierarchical clustering analysis (HCA) was conducted to cluster the questions into different groups. The smaller groups inside each main cluster and the squared Euclidean distance between every pair of questions are also provided using a dendrogram and a proximity matrix, respectively.

3 RESULTS

We have divided the results of this study into four sections; presenting the analysis from the perspective of the instructors, students, and peer mentors, as well as from the results from the statistical analysis.

3.1 Final course grades and instructors' observation

Table 2 displays the distribution of final course grades for the Fall 2018, Fall 2019, and Fall 2022 semesters. Fall semesters were selected for comparison as historically there are differences in the student population taking Calculus I each term of the year. The implementation of whiteboard seminars began in Fall 2019 and continued in Fall 2022, while in Fall 2018, students attended an additional lecture-hour each week instead of the seminars. The course enrollment for Fall 2018, Fall 2019, and Fall 2022 was 308, 245, and 353 students, respectively. Students who did not complete the course were assigned a grade of "N." The grades D, F, and N are all considered failures as students with these grades do not meet the prerequisite requirements for enrollment in the subsequent Calculus II course.

Table 2: Comparison of students' grades.

	Fall 2018	Fall 2019	Fall 2022
A+, A, A-	10.32%	15.98%	17.35%
B+, B, B-	26.13%	31.97%	33.88%
C+, C, C-	34.19%	25.00%	23.70%
D, F, N	29.36%	27.05%	25.07%

Notably, the proportion of students earning a grade of D, F, or N (failing grade) in Fall 2022 decreased by 4.29% from Fall 2018 and 1.98% from Fall 2019. Moreover, in both Fall 2022 and Fall 2019, fewer students received a C grade, while significantly more students earned A and B grades than in Fall 2018.

The overall mean in Fall 2022 improved by approximately 2% compared to Fall 2019, indicating that whiteboard seminars have played a role in enhancing student performance. Furthermore, the improvement in grades in Fall 2022 compared to Fall 2019 suggests that modifications to the structure and organization of seminars have improved the program's design.

While it is clear that whiteboard seminars benefit all students involved, the decrease in failure rates is not as pronounced as we expected. The whiteboard seminar model seems to have an additional impact on average and hardworking students over their weaker or unengaged peers. Modifications to identify and target weaker or unengaged students early in the semester could increase the impact on the failure rate in future offerings.

Based on the interactions between instructors and students, the group work aspect of whiteboard seminars has a positive effect on students' sense of community and participation in the course. Through the seminar environment, students get to know approximately 30 of their peers, fostering community and building friendships. In addition to improving their understanding of the material, the student support network created in the seminar environment improves overall course engagement and outcomes.

3.2 Students survey

We collected survey responses from 263 undergraduate students in Fall 2022 and Spring 2023 who participated in the whiteboard seminars and analyzed the responses. Descriptive statistics for each question can be found in Table 3. Remarkably, all 15 items scored very highly on the mean, which indicates a high level of student satisfaction with the service provided by the seminars. For Q5, which is the reverse scored question, the mean was 3.34, further validating our previous claim about student satisfaction.

Depicted in Table 3a, the mean values of Q7, Q8, Q9, and Q10 are close to the maximum positive response, thus indicating the substantial positive impact of peer tutors on the whiteboard seminars. Similarly, Q1, Q2, and Q3 demonstrate a high mode, mean, and median, indicating the importance of the instructor in the seminars. The positive feedback from the students in these areas emphasize the significant role of both the instructor and peer tutors to the success of the seminars.

Table 3: (a) Descriptive statistics for students' responses to each survey question, (b) descriptive statistics for each variable GP1-GP4.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
Mean	6.28	6.14	5.75	5.57	3.34	4.19	6.21	5.86	4.29	4.10	6.06	5.98	4.04	5.98	4.24
Median	7	6	6	6	2	4	6	6	4	4	6	6	4	6	4
Mode	7	6	7	6	1	4	7	6	4	4	7	7	4	6	5
Minimum	1	1	1	1	1	1	2	2	1	1	2	1	1	1	1
Maximum	7	7	7	7	7	5	7	7	5	5	7	7	5	7	5

	GP1	GP2	GP3	GP4
Mean	5.46	5.89	6.05	5.81
Median	5.60	6.00	6.00	5.75
Mode	6.40	5.60	7.00	7.00
Minimum	1.00	1.00	1.00	1.00
Maximum	6.40	6.40	7.00	5.25

The questions related to the learning factor and problem-solving techniques (Q2, Q6, Q8, and Q13) and indicators of student satisfaction (Q4, Q5, Q11, Q12, Q13, and Q15) all have high mode, mean, and median scores, indicating their overall success in the seminars.

The descriptive statistics of GP1-GP4, given in Table 3b, demonstrate a consistently high mean, median, and mode for each of the four variables. Hence, the descriptive statistics of the students' responses reveal that the seminars have been successful in all four of these factors.

Table 4: (a) Correlation between pairs of questions, (b) correlation between groups.

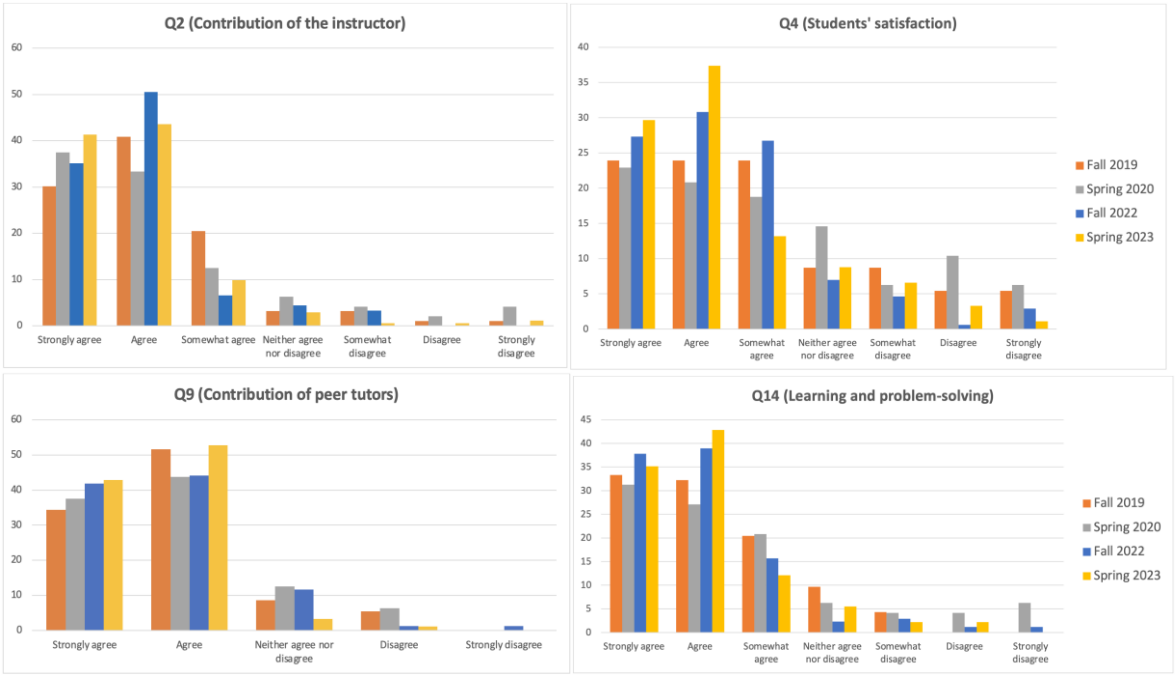
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
Q1	1.00	**0.64**	**0.74**	**0.56**	-0.35	0.37	0.26	0.22	0.28	0.37	**0.51**	0.26	**0.53**	0.46	0.36
Q2		1.00	**0.71**	**0.57**	-0.36	**0.56**	0.45	0.35	0.37	0.48	**0.51**	0.33	**0.56**	**0.57**	0.48
Q3			1.00	**0.62**	-0.36	0.43	0.36	0.22	0.30	0.42	**0.58**	0.36	**0.55**	**0.56**	0.45
Q4				1.00	**-0.59**	0.45	0.47	0.36	0.40	0.45	**0.61**	0.39	**0.74**	**0.61**	**0.60**
Q5					1.00	-0.36	-0.34	-0.29	-0.28	-0.38	-0.44	-0.26	**-0.54**	-0.35	-0.37
Q6						1.00	0.40	0.26	0.43	0.42	0.39	0.30	**0.50**	0.47	0.43
Q7							1.00	**0.62**	**0.56**	**0.64**	0.46	0.42	**0.58**	0.44	**0.50**
Q8								1.00	**0.62**	**0.65**	0.46	0.27	0.47	0.32	0.38
Q9									1.00	**0.69**	**0.51**	0.38	**0.50**	0.46	0.45
Q10										1.00	**0.59**	0.41	**0.59**	0.46	0.48
Q11											1.00	0.36	**0.64**	0.48	**0.51**
Q12												1.00	0.47	0.41	**0.59**
Q13													1.00	**0.60**	**0.61**
Q14														1.00	**0.58**
Q15															1.00

	GP1	GP2	GP3	GP4
GP1	1.00	**0.76**	**0.64**	**0.63**
GP2		1.00	**0.74**	**0.77**
GP3			1.00	0.44
GP4				1.00

Table 4a provides the correlation of each pair of questions. Items with a correlation greater than or equal to 0.50 are bolded. The matrix shows that Q1, Q2, and Q3, questions describing the instructor's performance, are significantly correlated. Moreover, Q7, Q8, Q9, and Q10, questions emphasizing the peer tutors' contribution to whiteboard seminars, are highly correlated and have a relatively weak correlation with the questions describing the role of the instructor in the seminars. This suggests that these two factors are somewhat independent of each other.

Table 4b shows the correlation matrix of the four variables GP1-GP4. The highest correlation coefficient is observed between GP1 and GP2, indicating that the whiteboard seminars provide an enjoyable environment for students to learn calculus concepts and problem-solving techniques. Furthermore, the strong correlation between GP3 (or GP4) and GP1 and GP2 indicates that students perceive their interactions with the instructor (or peer tutors) in a positive way in the whiteboard seminars. However, the weaker correlation between GP3 and GP4 again suggests that the contributions of the instructor and peer tutors are relatively independent of each other, and influence the seminars in different ways.

Figure 1: Comparative analysis of *survey results from Q2, Q4, Q9 and Q14 for Fall 2019, Spring 2020, Fall 2022, and Spring 2023.*



3.2.1 Comparison with the previous surveys

We conducted a comparative analysis of data received in Fall 2022 and Spring 2023 with data collected in Fall 2019 and Spring 2020. Our findings suggest that there has been a notable improvement in students' responses across almost all areas during the evolution of the seminars since their inception, as shown by the change in student responses in the surveys. Figure 1 shows the results of students' responses to Q2, Q4, Q9 and Q14 which were selected to represent the factors GP1-GP4 respectively. The bar charts provided demonstrate an upward trend in students' positive responses towards all four primary aspects of the seminars; students' satisfaction, learning, and

interaction with the instructor and peer tutors. The results presented in Figure 1 show that the whiteboard seminars have played a crucial role in establishing a collaborative and comfortable learning atmosphere for the students. The evolution of the seminars has facilitated improvements to effective learning and engagement with calculus concepts, which, in turn, will improve students' academic success.

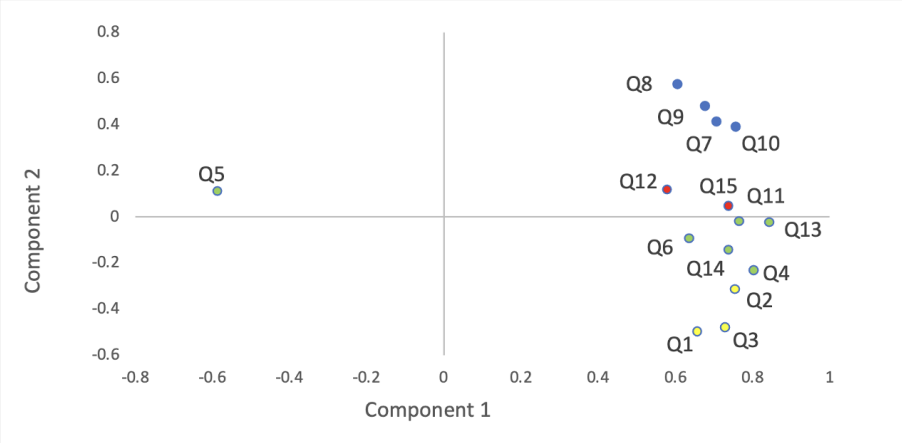
3.2.2 Exploratory factor analysis

Exploratory factor analysis (EFA) is a statistical technique used to identify underlying factors or latent variables that explain the patterns of correlations observed among a set of variables. It is often used in social science, education, and psychology research to explore the underlying structure of a large set of variables and to reduce the variables into a smaller set of meaningful factors. EFA allows us to better understand the relationships among variables and to identify which variables are most important in explaining the underlying construct of interest.

Bartlett's test of sphericity and the Kaiser-Meyer-Olkin test are commonly used to evaluate the suitability of data for exploratory factor analysis. Bartlett's test gave a value of approximately 0.00, and the Kaiser-Meyer-Olkin test returned a value of 0.93, indicating that EFA was appropriate for our data set. EFA yielded three significant components with eigenvalues 7.55, 1.57, and 0.93, respectively. The components explain 50.34%, 10.44%, and 6.19% of the total variance, respectively. The correlation between the three components and the questions is depicted in Figure 2b. In the table, correlations with an absolute value less than 0.2 are suppressed.

In Figure 2b, considering that Q5 is reverse scored, we see that all the questions are highly correlated to the first component. Therefore, one can safely say that the first principal component describes the success of whiteboard seminars in achieving all its four primary goals; students' satisfaction, learning calculus concepts and problem-solving techniques, the contribution of the instructor, and the contribution of the peer tutors. Comparing the extracted components with the questions, we see that Component 2 is positively correlated to the questions describing the role of peer tutors and negatively correlated to the questions describing the contribution of the instructor. Hence, we can consider Component 2 as the difference between the contribution of peer tutors and the contribution of the instructor. This component may suggest factors such as age, experience, or relationship to the students as an impact. However, more analysis is required to determine the exact indicator of this component. The positive correlation between Q12, Q15, and Component 3 suggests that Component 3 is a potential indicator of students' enjoyment of working on the vertical whiteboard surfaces.

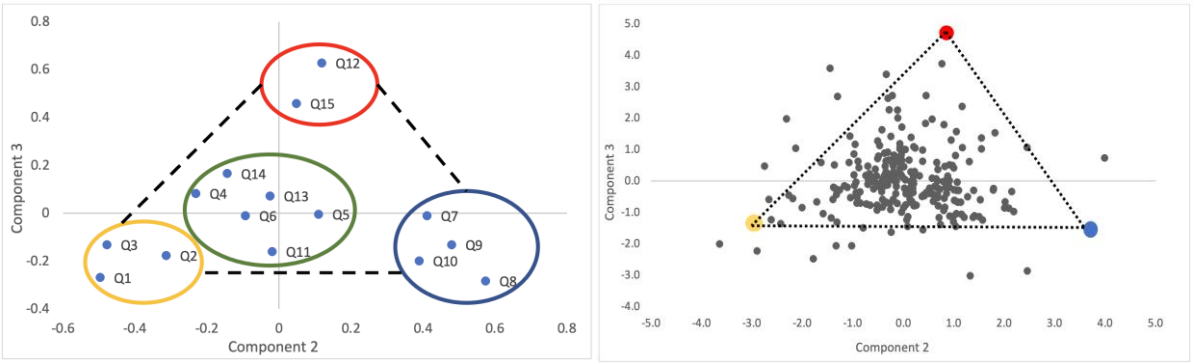
Figure 2: (a) distribution of questions in the component 1-component 2 space, (b) Correlation between components and survey questions.



	Component		
	1	2	3
Q1	0.66	-0.50	-0.27
Q2	0.76	-0.31	
Q3	0.73	-0.48	
Q4	0.80	-0.23	
Q5	-0.59		
Q6	0.64		
Q7	0.71	0.41	
Q8	0.61	0.57	-0.28
Q9	0.68	0.48	
Q10	0.76	0.39	-0.20
Q11	0.77		
Q12	0.58		0.63
Q13	0.84		
Q14	0.74		
Q15	0.74		0.46

Figure 2a plots the distribution of questions in the 2D component space. Since all questions (except Q5) are more positively correlated to Component 1 than Component 2, they are clustered near the Horizontal axis. In the component space of Figure 2a, the questions were categorized into four distinct groups: yellow (representing the instructor's contribution), blue (representing the peer tutor's contribution), red (representing enjoyment of activities on whiteboard surfaces), and green (representing learning and enjoyment of students). The colors yellow and blue serve as indicators for Component 2 (with reversed impact), the color red serves as an indicator for Component 3, and the remaining questions are shown in green. We will utilize this color-coding consistently throughout the paper.

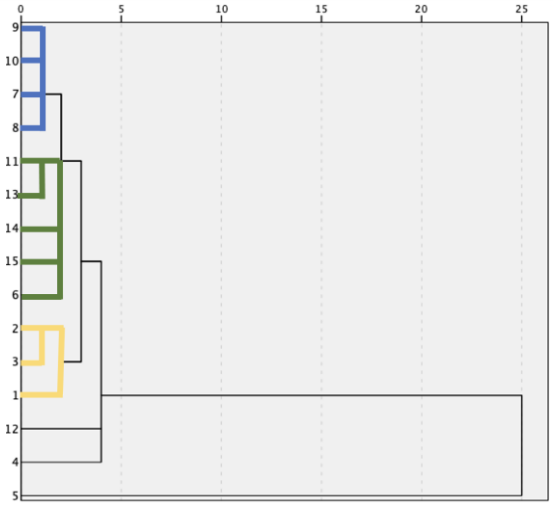
Figure 3: (a) Distribution of questions and (b) Distribution of students' responses in the 2D component space



A second 2-dimensional component space using Components 2 and 3 is provided in Figure 3a. The arrangement of questions in Figure 3a further emphasizes the close proximity of the four color groups of questions. These color groups of questions correspond to our measurement factors, namely GP1-GP4. An intriguing finding from Figure 3a is that, based on student responses, the learning and happiness of students are encompassed within a triangle formed by the enjoyment of activities on the vertical whiteboard surfaces, the contribution of instructors, and the contributions of peer tutors. This suggests that a happy learning process occurs in the seminars as a synergistic combination of these three factors. The proximity of the green and yellow groups indicates the significance of instructors in the learning and enjoyment of students.

Figure 4: (a) The squared Euclidean distance between each pair of questions, (b) dendrogram showing clusters formed according to Euclidean distances.

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
Q1	0	48	60	93	444	70	85	106	80	75	65	96	67	75	72
Q2		0	46	79	387	47	67	86	72	62	60	87	59	57	62
Q3			0	62	350	83	97	109	103	87	66	96	70	67	87
Q4				0	346	87	97	94	101	85	71	101	53	67	80
Q5					0	378	401	315	388	371	387	379	378	369	420
Q6						0	64	85	55	59	69	81	57	64	60
Q7							0	54	47	44	67	73	56	74	61
Q8								0	52	47	70	100	69	87	88
Q9									0	38	58	77	61	64	60
Q10										0	48	74	50	64	62
Q11											0	79	48	63	60
Q12												0	71	78	56
Q13													0	57	53
Q14														0	56
Q15															0



In future, more attention should be paid to the interaction between the instructor and the peer tutors, to positively reinforce their collaboration and thus, provide better support to the students, encouraging them to engage with a problem even if it is seemingly hard. In the seminars, peer tutors act as a "first line of defense" when students are attempting to solve the problem. In the end, it is still the instructor who is evaluating correctness of work. The distance between the enjoyment of learning and GP4 could benefit from additional research to improve this component.

Figure 3b depicts the distribution of all student responses in the 2D space of Components 2 and 3, obtained through a principal component analysis in R software. The plot shows that almost 94% of the responses are clustered within the triangle of happy learning, as previously discussed.

3.2.3 Hierarchical clustering analysis (HCA)

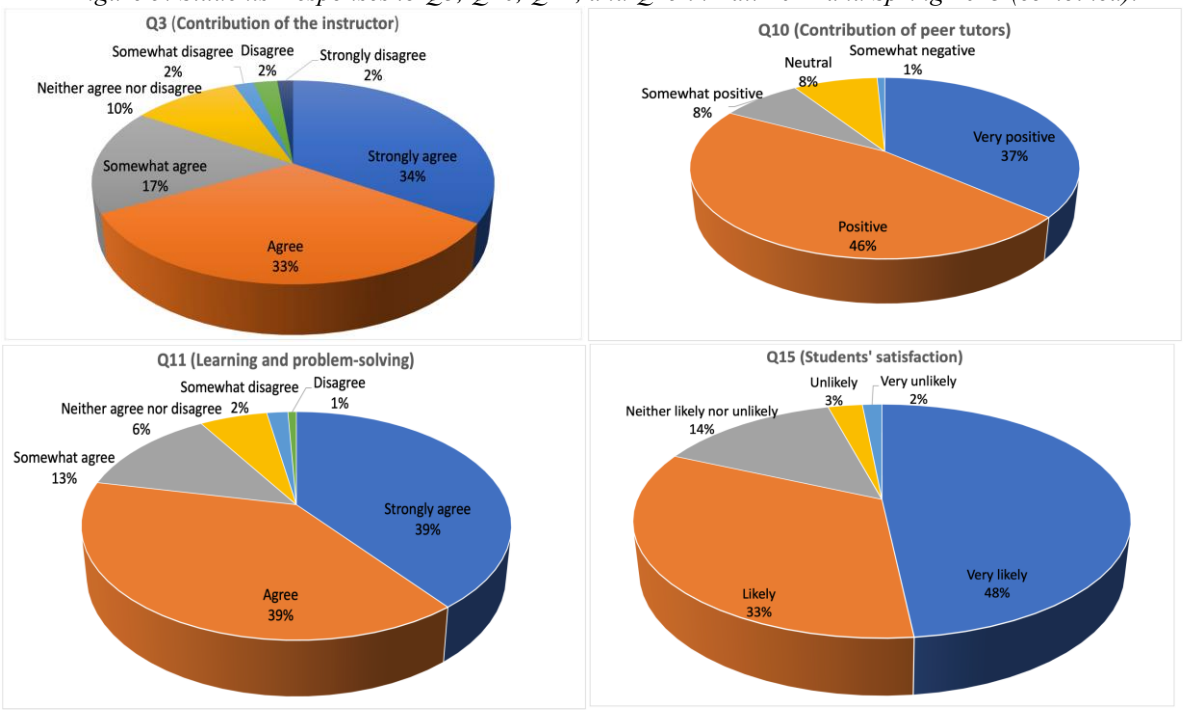
In general, hierarchical clustering helps to identify clusters of similar variables and to determine the characteristics of each cluster. The squared Euclidean distance between each pair of questions is given in Figure 4a. The maximum and minimum distances are between Q1 and Q5 and Q9 and Q10, respectively. The extensive distance between Q5 and all other questions shows that the seminar's activities are not stressful. Moreover, the close distance between the questions in each of the groups identified in Figure 2a is visible in Figure 4a.

The first two groups formed by HCA are questions regarding the peer tutors' and instructor's contributions. This clustering result verifies the instructor and peer tutors as the two main components of the seminars' success. A dendrogram is used to express the result of HCA in Figure 4b, which shows the clusters. The vertical axis is rescaled such that the minimum distance is 1 and the maximum distance is 25. In Figure 4b, Q9 and Q10 are clustered first due to the minimum distance among the questions. After that, additional questions either formed a new group or joined the previous group based on their distance from the previous questions. The dendrogram presents a clear correspondence between the first three clusters and the three groups identified in Figure 2a.

3.3 Students' observation

Students who participated in the whiteboard seminars reported that they had a positive experience that improved their understanding of course material, helped them achieve better grades in midterms and assignments, and found the seminars enjoyable.

Figure 5: Students' responses to Q3, Q10, Q11, and Q15 in Fall 2022 and Spring 2023 (combined).



The survey data for Q3 and Q9 given in Figure 5 indicates that less than 6% of students disagreed with the availability of the instructor and peer tutors to provide learning support when students encountered difficulties in approaching a problem. Additionally, the data from Q11 showed that students found the seminars to be a friendly environment where they could ask questions comfortably. Furthermore, only about 5% of students expressed reluctance to enroll in another class with vertical whiteboard activities, according to the responses to Q15. These four questions, which provide an overview of the four main factors, GP1-GP4, provide further evidence of the effectiveness of whiteboard seminars in all key areas, according to students' perspectives.

Students also provided feedback on potential areas for improvement. Suggestions included increasing the size of the vertical whiteboards, having more peer tutors in the seminars, and working in smaller groups.

3.4 Peers' observation

In total, 49 peer tutors participated in the whiteboard seminars in Fall 2022 and Spring 2023, and their feedback was overwhelmingly positive. Over 98% of the peer tutors found the seminars to be effective in improving students' achievement in the calculus course, and more than 98% believed that their own skills in explaining mathematical concepts were improved as a result of their involvement (Figure 6a). The peer tutors also reported that the seminars increased their confidence and preparedness for future coursework and employment (Figure 6b). Additionally, over 90% of the peer tutors found the seminars enjoyable and expressed their intention to participate in similar activities in the future. These findings demonstrate the positive impact of the whiteboard seminars on the peer tutors in addition to the students.

Figure 6: (a) My experience as a peer tutor has improved my ability to communicate and explain mathematical concepts (left), (b) My experience as a peer tutor has helped me prepare for future job opportunities (right).

According to peer's feedback, attending the seminars helped them feel more engaged in the university community, which was a rewarding experience. Peer tutors also had a positive experience collaborating with other peer tutors and students, which led to the formation of new friendships. The seminars provided a unique opportunity for students and peer tutors to gain experience working collaboratively, which fostered a sense of community among all participants.

Furthermore, peer tutors noted that the whiteboard seminars helped them improve their teaching skills by giving them the opportunity to explain concepts in simple terms to others. Additionally, peer tutors had the chance to work alongside top professors while assisting first-year students in a similar position to themselves. The seminars taught the peers about the importance of patience and effective teaching methods.

4 CONCLUSIONS

In this paper, we discussed the whiteboard seminars as a student-centered learning environment for a first-year calculus course at Simon Fraser University. Building on previous work, we extended the analysis by discussing the impact of the whiteboard seminars on both students and peer tutors, and conducting a statistical analysis of the survey results.

The whiteboard seminars showed significant improvements in student engagement and satisfaction due to increased interaction with classmates, peer tutors, and instructors. We observed students acquiring the necessary skills to solve problems from a resource-rich or choice-affluent environment. Working in groups at vertical whiteboard surfaces, students were able to access and integrate personal experiences, knowledge and ideas of their collaborators, expert knowledge of the instructor and peer tutors, and work collaboratively. Student surveys supported these findings, as students responded positively regarding interactions with instructors and peer tutors, had an increased understanding of course material, and expressed enjoyment of the whiteboard seminars. Although the overall grade improvement was not pronounced, we believe the acquired problem-solving skills and positive attitude through this program will lead to better class performance in subsequent mathematics courses.

Peer tutors noted that the whiteboard seminars helped them improve their teaching skills and were effective in improving students' achievement in the calculus course. Peer tutors also believed that their communication skills in explaining mathematical concepts improved. The seminars increased peer tutors' confidence and their perceived preparedness for future coursework and jobs.

The statistical analysis of the surveys verified the role of whiteboard seminars in the improvement of students' collaboration and learning. The exploratory factor analysis identified three latent components of the seminars: overall success, the importance of the instructor and peer tutors in facilitating student learning, and the students' preference for working on vertical whiteboard surfaces. Other statistical tests that were implemented supported our observations. As a result of this positive experience, the instructors plan to continue this model in future course offerings, and the Department of Mathematics at Simon Fraser University is considering modifying student help centers, or Workshops, to a similar model with more active student engagement on whiteboards.

In the future, in addition to continuing our current line of research, we plan to conduct a systematic study on the effects of seminars on the peer tutors. We believe that implementing specific strategies for selecting and training peer tutors could significantly improve the effectiveness of seminars and better prepare the tutors for future activities.

ACKNOWLEDGEMENTS

The authors would like to express our gratitude to Dr. Sophie Burrill from the Department of Mathematics at Simon Fraser University for her invaluable contributions in establishing the Calc Connect peer tutor program and creating various learning resources.

Furthermore, the authors would like to acknowledge the support provided by the Faculty of Science at Simon Fraser University under the 2022 Faculty of Science Teaching and Learning Grant "Whiteboard seminars in MATH-150: enhancing the student experience in a calculus course".

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