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Mastery Grading in Calculus: effects on performance and perception across demographics

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Abstract: This study examines the long-term effects, demographic impacts, and perception changes from two years of mastery grading in a Calculus I course. Previous findings showed notable benefits from mastery grading for students with the lowest diagnostic scores entering Calculus I. In this phase, we tracked the fall 2023 Calculus I cohort into Calculus II and III, noting that the benefits of mastery grading did not persist, possibly due to the shift to traditional grading and limited opportunities for tackling complex, integrative problems in the mastery approach. Although Calculus II scores appeared lower for the mastery-graded group, a disproportionately higher number of traditionally graded students dropped out, and those who dropped out had lower Calculus I final exam scores. Additionally, analysis of the Fall 2024 Calculus I cohort showed that mastery grading helped foster a growth mindset and reduce test anxiety, especially for minority groups (Female, URM, and First-Gen students). However, some subgroups showed notable patterns, such as female students experiencing a slight decline in disciplinary identity and URM students reporting reduced disciplinary sense of belonging over time. These trends, though not statistically significant, highlight the need for targeted efforts to better support these groups.

Keywords: Calculus, mastery grading, long-term effects, student success, student perception

Introduction

Alternative grading practices have been increasingly adopted in STEM education due to its focus on student growth and well-being. Mastery grading, as one of the alternative grading approaches, breaks course material into specific learning targets, and students are allowed multiple attempts to demonstrate mastery in each learning target [1]. The goal is to create a supportive and inclusive environment where students can achieve mastery at their own pace and to foster a growth mindset by emphasizing continual learning over grades. Research has highlighted several positive impacts of alternative grading approaches, particularly in reducing student stress. Instructors and researchers found that students experience less stress or anxiety during timed assessments, and they appreciate the opportunities to reattempt the concepts, without being penalized for early mistakes [2].

Calculus I, a gateway course for engineering students, has been shown to be a critical factor in predicting their success in engineering programs [3]. However, students entering Calculus I often have a wide range of preparedness levels. Many feel anxious about their grades and lack confidence, and a sense of belonging in the classroom [4]. These challenges make Calculus I a good candidate for exploring alternative grading practices.

Mastery grading was introduced in our engineering school's Calculus I course in Fall 2022, to address disparities in student preparedness and to reduce anxiety and build confidence. By Fall 2023, the study expanded to include more sections and a refined grading system. Our preliminary findings from earlier studies showed that students in the mastery-graded classes experienced reduced test anxiety, earned higher letter grades through penalty-free reattempts, and felt more confident in their math abilities [5]. While no significant difference was found in their end-of-semester performance compared to their peers in the traditionally graded courses, the common final exam results showed notable benefits from mastery grading for students with the lowest diagnostic scores entering Calculus I. We found that students in the lowest placement score category showed the biggest gains from the mastery grading system [6].

Despite its growing popularity, there remains a gap in longitudinal studies assessing the long-term effects of alternative grading on student performance. While prior studies have examined its immediate benefits within a course, few have investigated whether mastery grading prepares students for success in subsequent courses that revert to traditional grading schemes. Similarly, little is known about how mastery grading influences students' perceptions across different demographic groups during the semester in which they take a mastery-graded course.

Purpose and Research Questions:

To address these gaps, this study examines the implementation of mastery grading in a Calculus I course at an engineering school over two academic years. It investigates how mastery grading impacts students' performance in subsequent courses and its effects on their identity, self-efficacy, growth mindset, sense of belonging and test anxiety, with particular attention to differences across demographic groups.

This study, which received approval from IRB, is currently ongoing, with data collection spanning the fall 2023 cohort and the fall 2024 cohort. This phase of the study was guided by two research questions:

1. How do students from a mastery-graded course perform in subsequent courses, compared to peers in traditionally graded courses?
2. How does mastery grading impact students' perceptions of disciplinary identity, self-efficacy, growth mindset, sense of belonging and test anxiety over the semester, particularly across different demographic groups?

Overview of the Grading Design

Mastery Grading Scheme
The mastery grading design is structured around clear learning targets, with 26 targets in total, including 10 core targets. Students demonstrate mastery through weekly checkpoints, receiving marks of "mastered" or "progressing" and can reattempt each target over three subsequent checkpoints or designated reassessment sessions. Mastery is achieved upon earning two "mastered" marks per target. Grades are determined by the number of mastered targets, worksheet completion, and WebAssign performance, with an opportunity to adjust grades through a cumulative final exam.

Traditional Grading Scheme
Students in the traditional group were taught the same material as the mastery graded group. They had the same homework assignments and the same cumulative final exam. However, traditionally assessed students had three tests, all of which were graded with a traditional points-based and partial credit system. Their final grades were determined by the weighted average of worksheets, homework assignments, tests, and the final exam.

Methods

This study was carried out at the engineering school of a four-year, research-intensive public university in the Mid-Atlantic with roughly 22,000 students.

Participants
To answer research question 1, the long-term effects of the mastery grading system, we analyzed the performance of the Fall 2023 students across five Calculus I sections taught by three different instructors. Among these, three were taught using the mastery grading approach, while the remaining two were taught using a traditional grading scheme.

The same cohort of students progressed to Calculus II in Spring 2024 and Calculus III in Fall 2024, with the following completion numbers:

- Fall 2023 (Calculus I): 157 students, with 55 enrolled in traditionally graded sections and 102 enrolled in mastery graded sections.
- Spring 2024 (Calculus II): 133 students, all enrolled in traditionally graded sections.
- Fall 2024 (Calculus III): 70 students, all enrolled in traditionally graded sections.

To answer research question 2, the impact of mastery grading on students' perceptions across demographic groups, we analyzed students' matched pre/post survey responses (n=45 of 73, 62%) from two Mastery graded Calculus I sections taught by one instructor in Fall 2024.

Data Collection
Data sources included placement test scores and final exam grades from the Fall 2023 Calculus I cohort, tracking their performance in Calculus I, II, and III. Additionally, pre-course and post-course survey data were collected from the Fall 2024 Calculus I cohort, asking questions about identity, self-efficacy, growth mindset, and sense of belonging selected from previously validated instruments [7], [8]. It also included 5 test anxiety questions that ask students to report how frequently they experience symptoms of anxiety before, during and after tests, using a 5-item test anxiety inventory [9]. Survey data were matched to students' sociodemographic data (gender, race, first-generation status).

Data Analysis
To answer research question 1, Welch's t-test at a significance level of 0.05 was used to determine if there was any difference in the students' performance on the common final exam in Calculus I, II, and III. Chi-square test and z-test were used to examine the differences in grade distributions between mastery graded and traditionally graded Calculus I groups. Additionally, multiple regression analysis was conducted to examine how grading method and pre-calculus placement scores influence final exam performance, while accounting for differences in initial math preparedness.

To answer research question 2, we ran a paired t-test to identify changes in perceptions over time and an ANCOVA to identify end-of-semester differences in perceptions by sociodemographics while controlling for pre-survey perceptions.

Results

Question 1: How do students from a mastery-graded course perform in subsequent courses, compared to peers in traditionally graded courses?

Final Exam Comparisons

Below is the summary of the statistics comparing the mastery group and traditional group performance across final exams for Calculus I, II and III. Of the 157 students who completed Calculus I in Fall 2023, 133 took Calculus II in Spring 2024 and only 70 completed Calculus III in Fall 2024. There was not a statistically significant difference between the groups in Calculus I and III, but the traditional group outperformed the mastery group in Calculus II.

- Calculus I: The mastery and traditional groups showed a very similar performance (means 78.26 vs. 79.01), with a high p-value (0.78) indicating no statistically significant difference.

Calculus I Final	Mastery	Traditional
Mean	78.26	79.01
SD	1.56	2.23
Observations	102	55
p-value	0.78	

- Calculus II: The traditional group averaged higher (81.71) than the mastery group (75.46), and this difference was statistically significant (p = 0.04).

Calculus II Final	Mastery	Traditional
Mean	75.46	81.71
SD	1.88	2.39
Observations	89	44
p-value	0.04	

Here we note that 25 (of 157) students from the 2023 Calculus I cohort did not successfully complete Calculus II the following Spring. Sixteen of these did not attempt the course, with 11 (69%) from the traditionally graded group. Nine others took the first exam in Calculus II but did not make it as far as the final exam; of those, only one of those was from the traditional group. In other words, of those who did not take the final exam (either because they did not move on to Calculus II at all or withdrew from the course before taking it), 12 (48%) were in the traditionally graded group while 13 (52%) had been in the mastery group. Considering that the original cohort had 55 students (35%) in the traditional group and 102 (65%) in the mastery group, this indicates that the traditional group disproportionately did not complete the final exam. The drop-out rate was 22% for the traditional group compared to 13% for the mastery group. The figure below compares the drop-out rates.

Drop-out Rate Comparison	Mastery	Traditional
Students enrolled in Calculus I	102	55
Non-completers in Calculus II	13	12
Drop-out Rate	13%	22%

Moreover, examining the Calculus I final exams for these 25 students who did not take the Calculus II final, we find that the average of the 12 traditionally graded students was 65.0% compared to the average of the 14 mastery graded students, which was 68.2%. In other words, students from the traditionally graded group who had "missing" scores in the Calculus II data had performed worse in Calculus I than those in the mastery graded group.

We speculate that the absence of this data could be influencing the observed difference in the final exam averages in that students with the lowest scores in the traditionally graded group were much more likely to disappear from the data in the next course than their counterparts in the mastery graded course.

- Calculus III: While the traditional group's average (66.97) was numerically higher than the mastery group's (61.94), the difference was not significant ($p = 0.19$).

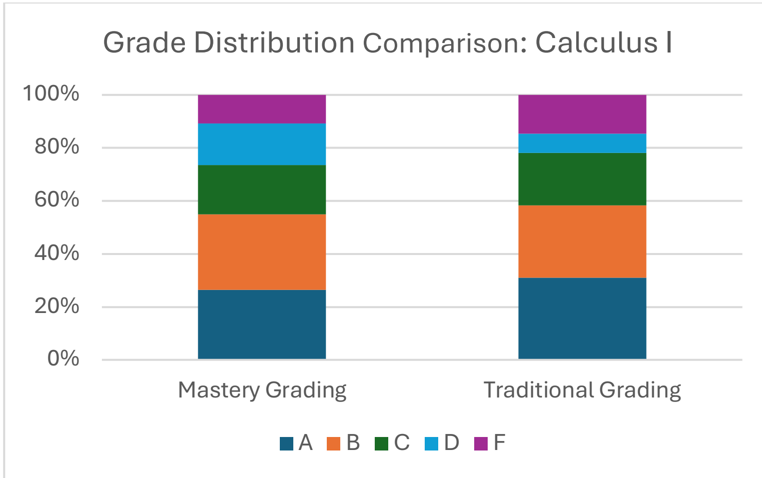
Calculus III Final	Mastery	Traditional
Mean	61.94	66.97
SD	2.06	3.15
Observations	45	25
p-value	0.19	

It is worth noting that fewer than half of the original cohort completed Calculus III in Fall 2024. This was due to several factors, including students taking Calculus during summer 2024 at our institution or another (since most engineering students at our institution begin in Calculus II or III, students who instead begin in Calculus I feel some urgency to "catch up" to their peers), transferring to different schools or dropping out.

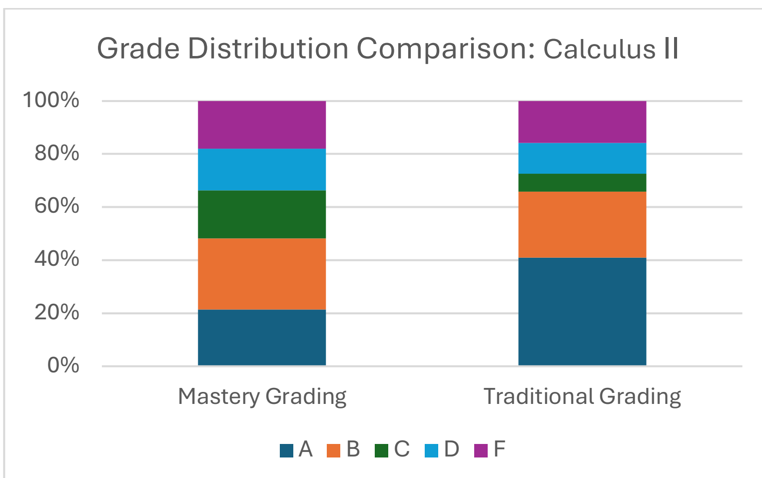
Grade Distribution Comparison

To examine whether students from mastery graded and traditionally graded Calculus I sections had the same grade distribution in subsequent courses (Calculus II and III), we conducted a Chi-Square test, comparing the distribution of final exam grades (A, B, C, D, F) across two groups (Mastery vs. Traditional).

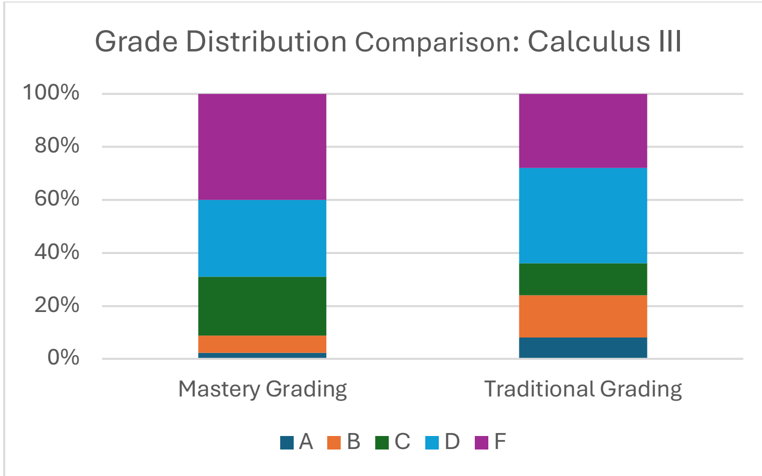
- Calculus I (p-value=0.41): The Chi-Square test showed no significant difference in grade distributions between students in Mastery vs. Traditional grading sections. This suggests that the grading method in Calculus I did not impact final grade distribution.



- Calculus II (p = 0.02): A significant difference in grade distribution was found between students from mastery graded and traditionally graded Calculus I sections. To look more closely, we also performed pairwise Z-tests for each grade category. It showed that traditionally graded students had a significantly higher percentage of A's in Calculus II (p = 0.02), while no significant differences were observed in other grade categories.



- Calculus III (p = 0.22): The Chi-Square test found no significant difference, indicating that both groups performed similarly in Calculus III, regardless of their prior grading method.



Final Exam Performance by Placement Score

Next, we compared student performance on the Calculus I, Calculus II and Calculus III final exams by the initial pre-calculus placement score to establish whether students with different preparation levels entering the university scored differently on these exams based on their grading system in Calculus I. Students were divided into subgroups based on their placement scores. The placement test included 30 pre-calculus questions, and each question is graded on a 1-point scale. Final exam score averages are provided for each range of placement test scores, along with the number of students in each category.

It's important to note that prior to comparing students' performance by subgroups, we first examined whether there were significant differences in their placement scores between the two grading groups. The result shows that students in the traditional group generally entered with stronger preparedness, which could impact their performance in subsequent calculus courses.

- Calculus I: Among students who completed both pre-calculus placement and Calculus I final exams ($n = 144$), there was a significant difference in preparedness between the two grading groups ($p = 0.048$). Students in the traditional group had a higher average pre-calculus score (16.7) compared to the mastery group (15.1). Despite this initial difference, both groups performed similarly on the calculus I final exam ($p = 0.78$). This raises the possibility that mastery grading helped lower-performing students "catch up" to their traditionally graded peers by the end of the course.

  When we examined final exam performance by placement score subgroups, we observed that students in the lowest placement score category (<16) showed the biggest gain from the mastery grading system, outperforming their peers in the same category from the traditional group (mean: 78.7 vs. 73.5).

Calc I Final Exam Scores by Pre-Calc Placement Score			
	Less than 16 Mean (N)	**16-20** Mean (N)	**Greater than 20** Mean (N)
Mastery	78.7 (54)	76.9 (26)	84.3 (17)
Traditional	73.5 (16)	82.4 (24)	84.4 (7)

- Calculus II: For students who completed both pre-calculus placement and Calculus II final exams ($n = 123$), we again found a significant difference in pre-calculus scores ($p = 0.025$), with the traditional group scoring higher (16.8 vs. 14.9). This suggests that students in the traditional grading group entered Calculus II with a stronger pre-calculus foundation. As discussed in the previous section, in Calculus II, the traditional group significantly outperformed the mastery group on the final exam (81.71 vs. 75.46, $p = 0.04$). This suggests that differences in preparedness may be a contributing factor to the performance gap between two groups.

  The final exam scores increased with placement scores in the mastery graded sections, as we would expect, given the strong influence of background knowledge. In each placement score group, the traditionally graded sections outscored the mastery graded students.

Calc II Final Exam Scores by Pre-Calc Placement Score			
Score on Placement Exam	**Less than 16** Mean (N)	**16-20** Mean (N)	**Greater than 20** Mean (N)
Mastery	74.0 (49)	75.8 (23)	81.4 (16)
Traditional	83.6 (11)	80.0 (21)	89.1 (5)

  Since the pre-calculus scores differ significantly between the grading groups, we also ran a multiple regression analysis to understand how grading method (Mastery vs. Traditional) and pre-calculus placement scores impact Calculus II final exam scores, and whether the effect of placement scores differs between grading methods. The overall model was statistically significant ($p = 0.015$) and these factors explained about 8.4% of the variation in final exam scores.

  Among the factors tested, pre-calculus placement score was the only significant predictor ($p = 0.014$). This means that students who scored higher in pre-calculus placement also tended to perform better on the Calculus II final exam. However, grading method did not have a significant effect on final exam scores ($p = 0.438$), suggesting that after accounting for differences in pre-calculus preparation, students from mastery and traditionally graded sections performed similarly. Additionally, the interaction between grading method and placement scores was not significant ($p = 0.675$), meaning that the effect of pre-calculus scores on final exam performance was consistent across both grading methods.

- Calculus III: Among students who progressed to Calculus III with available placement scores ($n = 64$), there was no significant difference in their placement scores between the two groups ($p = 0.51$), with the traditional group averaging 15.3 and the mastery group 14.6.

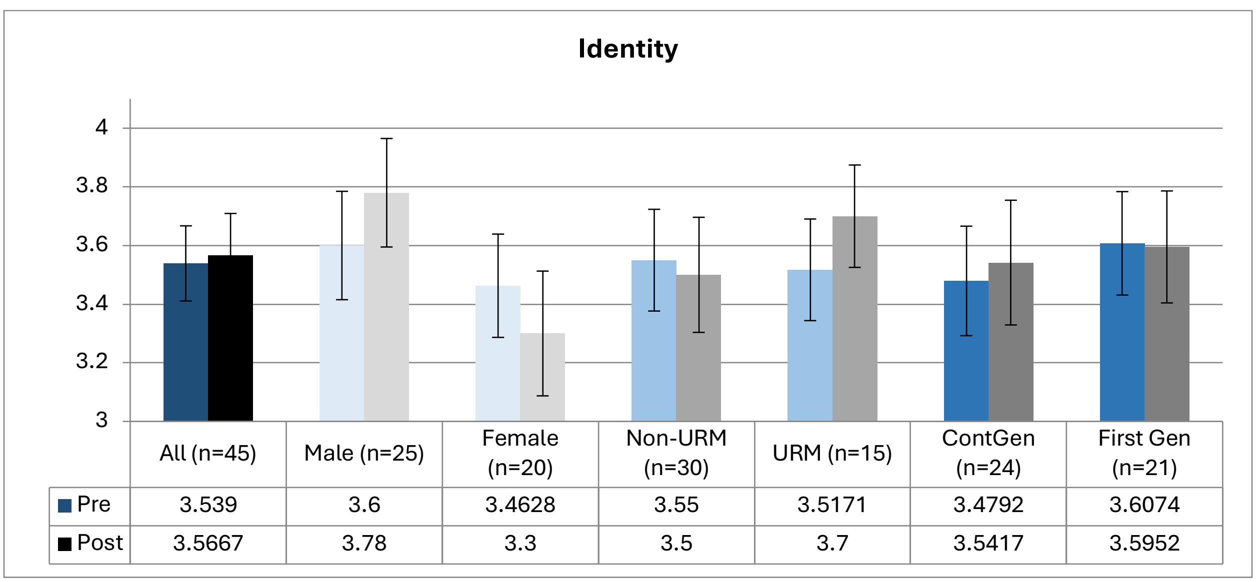
  Traditionally graded students outperformed mastery graded students on the Calculus III final in the high pre-calculus placement category but performed slightly worse in the lower category. Note that there are only two placement categories here due to the lower number of students.

Calc III Final Exam Scores by Pre-Calc Placement Score		
Score on Placement Exam	**Less than or equal to 14** Mean (N)	**Greater than 14** Mean (N)
Mastery	56.7 (21)	66.4 (22)
Traditional	55.5 (7)	73.2 (14)

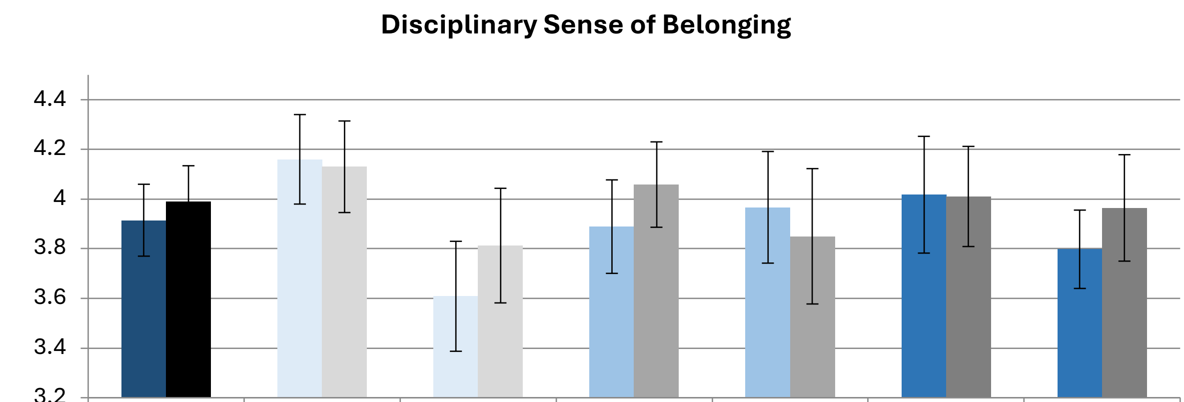
Question 2: How does mastery grading impact students' perceptions of disciplinary identity, sense of belonging, self-efficacy, growth mindset, and test anxiety over the semester, particularly across different demographic groups?

Below is a summary of the Fall 2024 survey findings, organized by perceptions. We describe the differences over time, followed by differences between demographic groups when controlling for pre-survey responses. We also provide bar graphs for each scale to illustrate changes in students' perceptions over time. These graphs are further broken down by gender (male/female), underrepresented minority status (URM/non-URM), and generational status (continuing generation/first generation). Each graph includes a table displaying the mean values along with standard error bars.

Disciplinary Identity: Most groups experienced a positive change in their disciplinary identity. However, female students showed a slight negative trend, though this was not statistically significant. There were no significant differences between students' perceived identity by URM at the end of the semester when controlling for pre-survey perceptions, nor for first generation and continuing generation students. However, there were significant end-of-semester differences between male and female students when controlling for pre-survey responses, $F(1,8.8)=5.296$, $p=.047$, $\eta=.375$.

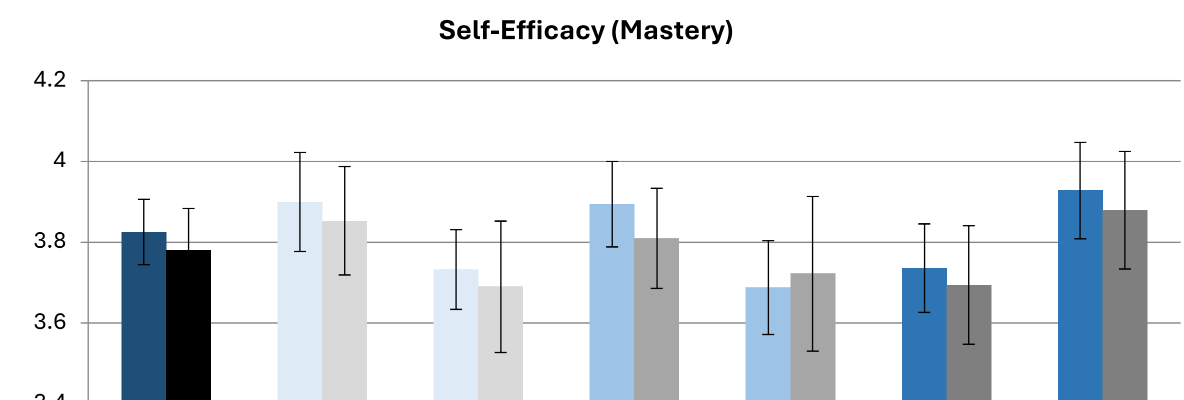


Disciplinary sense of belonging: While sense of belonging improved for most students, URM students exhibited a slight decline in this area. Similar to disciplinary identity, this change was not statistically significant. There were no significant differences between students' sense of belonging by gender or URM at the end of the semester when controlling for pre-survey perceptions.

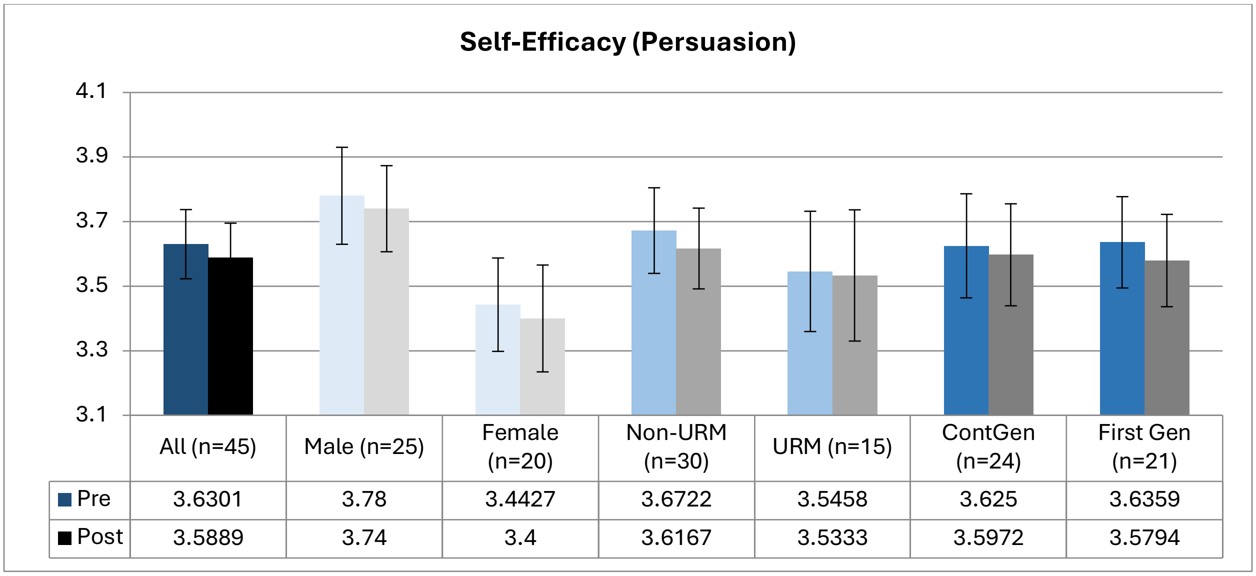


	All (n=45)	Male (n=25)	Female (n=20)	Non-URM (n=30)	URM (n=15)	ContGen (n=24)	First Gen (n=21)
Pre	3.9148	4.16	3.6084	3.8889	3.9667	4.0174	3.7977
Post	3.9889	4.13	3.8125	4.0583	3.85	4.0104	3.9643

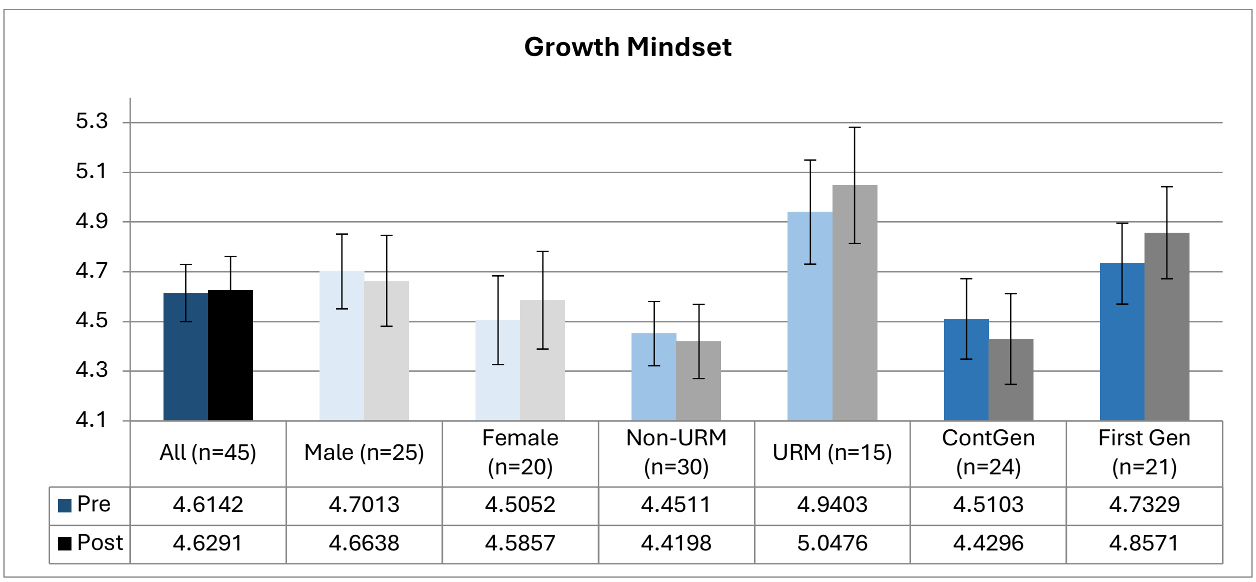
Self-efficacy: There were no significant changes in students' perceived self-efficacy in both mastery experiences and verbal persuasion measures over the semester, although a slight decline was noted across most demographic subgroups. There were no significant differences between students' self-efficacy (mastery) by gender, URM, or first-generational status at the end of the semester when controlling for pre-survey perceptions.



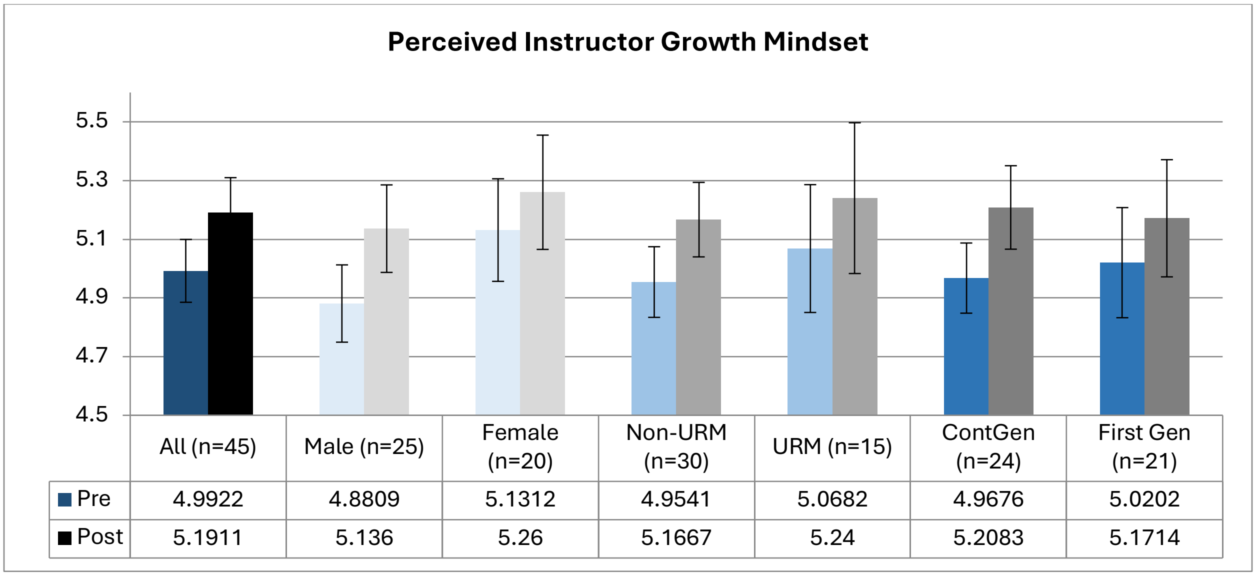
	All (n=45)	Male (n=25)	Female (n=20)	Non-URM (n=30)	URM (n=15)	ContGen (n=24)	First Gen (n=21)
Pre	3.8256	3.9	3.7327	3.8944	3.688	3.7361	3.928
Post	3.7807	3.8533	3.69	3.81	3.7222	3.6944	3.8794



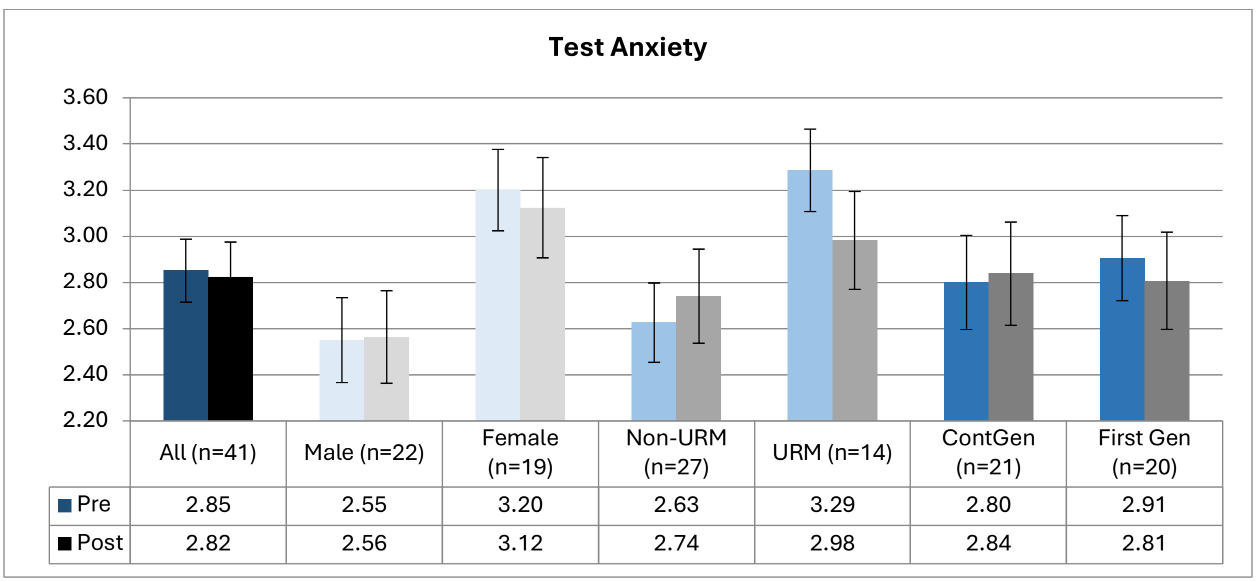
Growth Mindset: Students from all minority groups (Female, URM, First Gen) showed positive shifts in their growth mindset perceptions over the semester. This suggested an increased belief in their ability to improve their intelligence and skills through effort. There were no significant differences between students' growth mindset by gender, URM or first-generational status at the end of the semester when controlling for pre-survey perceptions.



Instructor mindset: Students also viewed their instructor as supportive of a growth mindset. The result indicated positive trends across all demographic groups. There were no significant differences between students' perceived instructor growth mindset by gender, URM, or first-generational status at the end of the semester when controlling for pre-survey perceptions.



Test anxiety: Students in all minority groups (Female, URM, First Gen) began the semester with higher level of test anxiety compared to their counterparts (Male, Non-URM, ContGen) but reported reduced test anxiety at the end of the semester. There were no significant differences between students' test anxiety by gender, URM, or first-generational status at the end of the semester when controlling for pre-survey perceptions.



Discussion

Mastery grading may provide immediate benefits, particularly for students with lower initial preparedness. However, these benefits might not persist in subsequent courses. One reason we might see this outcome is the shift to a traditional grading system in Calculus II and III. Students who were used to the mastery approach may not have adapted well to the different expectations and ways of being assessed in a traditional setting. The different assessment styles and expectations could impact their performance. Plus, the mastery grading structure and assessment approach may not have offered sufficient opportunities for students to engage with complex problems requiring the integration of multiple skills. By focusing primarily on individual learning targets and assessing them in isolated units, students may have been less prepared for the challenges of Calculus II and III.

On the other hand, while the Calculus II scores were ostensibly lower for the mastery graded group, disproportionately more traditionally graded students dropped out before completing that course, and those who did drop out had obtained lower final exam scores from Calculus I. Additionally, students in the traditional group entered Calculus II with significantly higher pre-calculus score, and we found that higher placement scores were associated with better final exam performance in Calculus II. This suggests that students' precalculus preparedness played a crucial role in their performance, possibly more than the grading method itself.

Reflecting on our experiences and results, we identified two potential areas for improvement. The major issue to address is that the current structure of the learning targets requires us to assess material in discrete units. Students are not seeing connections between topics or practicing the all-important skill of integrating multiple strategies when approaching a problem. We want to add synthesis targets at various stages in the semester, helping students put together what they have learned so far and also have chance to tackle more complex problems.

For students' perceptions in Calculus I with the mastering grading scheme, we observed that the targeted interventions at fostering a growth mindset and reducing test anxiety are benefiting all minority groups (Female, URM and First-Gen). Over the course of the semester, students from these subgroups showed increased growth mindset and a decrease in test anxiety, and when controlling for pre-survey perceptions there were no differences in post-survey mindset and test anxiety between any subgroups of students. While most groups are moving in a positive direction with respect to their *disciplinary identity* and s*ense of belonging,* some subgroups (female students for *disciplinary identity*, and URM students for *disciplinary sense of belonging*), are moving in a negative direction. These patterns are not significant but warrant attention and further effort given opposite directions. In addition, the persistent gender differences in disciplinary identity highlight a need to better support female students' identity development in their disciplines. The findings from our analysis extend the alternative grading literature [10] [11] to provide additional evidence for the promise of alternative grading for student. Our study also contributes to the robust STEM education literature examining the impact of active learning and evidence-based instructional practices (EBIPs) on student mindset, sense of belonging, identity, and self-efficacy [12] [13] [14] to understand the potential impact of a grading approach on these perceptions.

Limitations and future work

One significant limitation in tracking this cohort of students through subsequent classes was the high number of students who did not complete the subsequent classes at the expected times. For example, fewer than half of the students from the original cohort took the Calculus III final exam during the Fall 2024 semester. Moreover, at the Calculus II stage, traditionally graded students were more likely to be absent from the data.

For future work, we would like to track the Fall 2024 cohort and find if the same patterns persist, particularly whether the traditionally graded group is less likely to complete the next courses. We would like to obtain a clearer picture of the D/F/W rates for each group as well, data that we were unable to obtain for the Fall 2023 group across all sections.

Also, because we conducted extensive pre-calculus testing for the Fall 2024 cohort, we hope to track their future performance by pre-calculus achievements. This should give us another measure of the potentially different effects of mastery grading on students with different levels of background knowledge.

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